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U. S. Department of Energy
Development of Risk- and Cost-Estimate Process
Pilot Study for the Office of Management and Budget

February 1992

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EXECUTIVE SUMMARY

The Budget of the United States Government, Fiscal Year 1992 contained a commitment to conduct risk-based budgeting pilot studies at several federal agencies. The Office of Management and Budget (OMB) requested that the U.S. Department of Energy (DOE) develop a risk- and cost-estimating process and apply it to subprojects within DOE's Office of Environmental Restoration (ER). It is important to recognize that DOE budgets will be developed to assure that all legal requirements are fully met, independent of any risk-based methodology.

OMB requested that the risk- and cost-estimating methods developed be tested in a pilot study of 24 subprojects within ER. The pilot study would rank the subprojects and remedial cleanup alternatives based on risk and risk reduction per dollar spent. OMB specified that health risk was to be determined based on risk to members of the general public as well as risk to remedial workers. Cost was to be determined based on the lifetime cost of implementing the remedial alternative at the sites.

In response to OMB's request, ER formed a risk team to estimate baseline health risk and risk reductions, and a cost team to develop and implement a process for estimating the costs of remedial actions. An important OMB requirement was for DOE to develop risk and cost estimates in as consistent a manner as possible given the many different remedial sites, environmental settings, and types of contamination within the DOE ER Program. OMB also required the use of a single method for risk estimating, a single process for cost estimating, and a consistent set of assumptions in order to achieve consistency in estimates.

OMB requested that for each subproject, the health risk and cost of a no-action alternative and three remedial alternatives were to be estimated. The 24 subprojects were to represent a wide variety of environmental settings and include subprojects containing various forms of remedial work within the ER Program. OMB further requested that the study include subprojects involving a wide range of waste release mechanisms. Finally, it was necessary to include sites that encompass various stages of characterization and contain environmental and source term data of different levels of quality readily available for developing risk estimates at the subproject level. Representatives of DOE and OMB visited each of the affected installations and briefed them on the nature, scope, and process of the study. Each installation was encouraged to critique the effort and to provide suggestions for improvement. In addition, each installation was requested to provide the most up-to-date documentation relating to subproject-specific risks and costs, as well as a best estimate of remedial alternatives most suitable for a particular subproject.

The human health risk-estimating model was chosen after a review of the risk-estimating models available to DOE. In order to meet OMB's desire for consistency in health risk analysis, the selected code must be capable of modeling the many different disposal methods, environmental settings, waste streams, release mechanisms, and remediation methods represented in the DOE complex. It was necessary to choose a code that estimated total population risk in addition to individual risk and provided realistic estimates of risk rather than upper bound estimates. Finally, because of the short period of the study and the extensive modeling necessary to estimate baseline health risk and risk reduction at 24 disposal sites, it was necessary to choose a model that had a pre-existing data base of environmental parameters relating to DOE installations. As a result, DOE and OMB agreed that the Multimedia Environmental Pollutant

Assessment System (MEPAS) would be used to estimate risk and that the study would serve as an evaluation of MEPAS.

The study found that MEPAS generally provides an adequate and objective evaluation of population risk, but several improvements are needed. The environmental transport portions of MEPAS are similar in construction to models recommended by EPA and the U.S. Nuclear Regulatory Commission (NRC). When applied to well characterized sites, MEPAS appears to produce results similar to those obtained during the Remedial Investigation/Feasibility Study (RI/FS) risk assessment process. The major difficulties with MEPAS for the present application are (1) under certain circumstances, MEPAS does not adequately estimate environmental releases of contaminants from the waste units, and (2) MEPAS cannot directly simulate certain remedial action alternatives, including capping and pumping of ground water.

The study predicts time-discounted baseline population risks ranging from zero to seven fatalities (over 7,000 years) per subproject within this 24 subproject analysis, with 83 percent of the sites having a predicted baseline population risk of less than one fatality. The predicted risk reduction achieved through remedial action varied considerably from complete reduction at some sites to a net increase in risk at others. The average cost of remedial action is predicted to be on the order of $100 million. As illustrated in Table 4.3(a), the predicted cost per discounted fatality avoided through remedial action is equal to or greater than $100 million at over half of the sites where remedial action reduces the number of predicted fatalities.

The primary conclusion of the study, as detailed within the report's tables and associated narrative, is that projected population and average individual risks over 7000 years from the 24 subprojects are small. Furthermore, risks associated with remediation of the 24 subprojects are generally comparable to existing baseline levels of risk to the surrounding populations. Thus, in many cases, the number of deaths in the worker population involved in remedial action is projected within this pilot study to be equal to or greater than the number of deaths avoided (through the implementation of currently available remedial alternatives) in the surrounding population over 7000 years. Another finding of the study is that worker risk associated with remediation results primarily from occupational accidents during the remediation process rather than from radiation exposures. These last two findings may not be generally applicable because of the pilot study's small sample and restricted scope and the limitations of currently available remediation technology and information from site characterization. However, these findings alert DOE to the need to continue to carefully assess projected occupational risks of proposed remediation alternatives and take measures to reduce them.

1. INTRODUCTION

1.1 BACKGROUND

The Budget of the United States Government, Fiscal Year 1992 contains a discussion of Risk Management Budgeting. The 1991 Risk Management Budgeting Initiative section identifies 11 pilot programs to use Risk Management Budgeting in developing the 1993 budget. The U.S. Office of Management and Budget (OMB) requested that the U.S. Department of Energy (DOE) develop a health risk-and cost-estimating process that could be used to evaluate DOE subprojects within the Environmental Restoration (ER) Program. OMB directed DOE to test this process in a Pilot Study involving 24 ER Program subprojects and further required that the subprojects be ranked by risk, and the remedial cleanup alternatives be ranked by risk reduction per dollar spent.

In response to this request, on June 10, 1991, DOE formed two separate teams to evaluate risks and costs at selected DOE ER subprojects. The risk team was organized to develop and implement a process for estimating (1) the baseline health risks of selected DOE ER subprojects, (2) the health risk reduction as a result of remedial activities at these sites, and (3) the health risk to workers directly involved in cleaning up the sites. Population baseline health risk and health risk reduction were to be measured as the total cancer-related fatalities surrounding the facilities. Health risk to workers was to be measured as the risk of fatality to remediation workers from occupational hazards and from radiation dose during remedial activities. Health risk to remediation workers due to chemical exposure was not modeled because it was determined that adequate health and safety measures would be implemented as a result of required health and safety plans to protect workers from chemical exposure. During the risk-estimating process, the risk team was directed to evaluate the methods used in developing risk estimates. The cost team was directed to evaluate, select, and implement a cost-estimating method and to use that method for estimating the total lifetime cost of remedial actions at waste disposal sites.

A single method for risk estimating and a single process for cost estimating was used to achieve consistency in estimates; this supported the use of a consistent set of assumptions for all sites and conditions. In addition, the same team members were used for risk and cost analyses in order to achieve consistency.

1.2 SCOPE AND ORGANIZATION OF REPORT

This report describes the process used to conduct the pilot study. As requested by OMB, the report also includes recommended modifications to that process. Evaluation results of the 24 selected DOE ER Program subprojects are presented along with the study's major assumptions. In addition, the report contains a detailed description of the implementation process for each of the subprojects.

This report is divided into five major sections and includes two appendices. An executive-level summary provides the primary conclusions of the Pilot Study. Section 1 contains a review of the background of this project, a description of the report's methodological framework, and a description of how the 24 subprojects were selected. Sections 2 and 3 present a detailed description of the risk- and cost-estimating models used in the study and the major assumptions contained within the models. Section 4 presents a summary of the analytical results of the study. Section 5 presents the conclusions and recommendations offered by the study's participants. Appendices A and B present detailed descriptions of the subprojects and the detailed analytical data in the study.

1.3 METHODOLOGICAL FRAMEWORK

Estimates of health risk and cleanup costs for ER subprojects are subject to considerable uncertainty, especially in the early stages of a subproject's life history. Because some sites are fully characterized (through the Remedial Investigation/Feasibility Study stage), whereas other sites have not yet been characterized, the quality of data used to generate the risk estimates varied considerably from site to site. The risk numbers as presently constituted should not be used to distinguish differential risk between specific sites, but rather to make broad site groupings with respect to risk.

The cost estimates include direct cost, such as field labor or sample analysis, indirect cost, such as contractor overhead and profit, and contingency with variability at each level. The cost risk factors that contribute to contingency are many and complex, and the contingency represents an allowance for omissions from the estimate attributable to incomplete design or unknown conditions, but does not provide for additional work not in the original scope of the project, such as the cleanup of an additional area. The contingencies included in cost estimates prepared for this study are based on professional judgement and follow guidance on this subject issued by DOE, including the Environmental Restoration and Waste Management Cost Assessment Team, Cost Estimating Handbook for Environmental Restoration and guidance issued by the DOE Director of Independent Cost Estimating. The probabilistic nature of risk, project management risk in this case, serves to emphasize the importance of recognizing that cost estimates are better expressed as a range of values than as point estimates.

1.4 SITE SELECTION METHODOLOGY

OMB specifically requested that the subprojects chosen for this study be representative of the remedial activities within the DOE ER Program. As a result, some of the subprojects had completed feasibility studies (FS) while others had not begun remedial investigations (RI). However, in all cases some characterization data were available. In addition, because of the representative sample, subprojects determined by site characterization to contain no risk were also included in this study.

The process of selecting the 24 DOE ER Program subprojects was closely tied to the choice of the risk-estimating model, the proposed ER Program Work Breakdown Structure (WBS), and the amount of time available to complete the project. The risk-estimating model selection process is described in Section 2.1. In order to complete the effort by October 1, 1991, those subprojects within the proposed ER Program WBS that resembled projects modeled during the Environmental Survey and that were aligned with existing Activity Data Sheets for those ER remediation activities were considered first.

Subprojects within the Uranium Mill Tailings Remedial Action (UMTRA) Program, Remedial Action subprojects, and Decontamination and Decommissioning (D&D) subprojects were also included in this study. To further meet OMB requirements, the subprojects were selected to reflect various environmental settings, waste release mechanisms, and waste types. Subprojects from both the eastern and western portions of the country, and those located in arid and humid climates were included. In addition, liquid releases as well as landfills and residual soil contamination sites were included.

The final list of subprojects included in this study is:

1. Operable Unit 1 of the Fernald Environmental Management Project
2. Operable Unit 4 of the Fernald Environmental Management Project
3. Site 300, Pit 6 at Lawrence Livermore National Laboratory
4. Site 300, Building 834 Complex at Lawrence Livermore National Laboratory
5. F&H Area Seepage Basin(s) at Savannah River Site
6. New TNX Seepage Basin at Savannah River Site
7. M Area Settling Basin at Savannah River Site
8. Sanitary Landfill Closure at Savannah River Site
9. Waste Area Grouping 6 at Oak Ridge National Laboratory
10. Bear Creek Operable Unit 4 at Y-12 Plant, Oak Ridge
11. Pond Waste Management Project at K-25 Plant, Oak Ridge
12. Building 9201-4 (Alpha 4) D&D at Y-12 Plant, Oak Ridge
13. 800 Area Landfill at Argonne National Laboratory, East
14. 570 Holding Pond at Argonne National Laboratory, East
15. Liquid Waste Process Area D&D at Argonne National Laboratory, West
16. BORAX-V Facility D&D at Idaho National Engineering Laboratory
17. LAPRE Reactor D&D at Los Alamos National Laboratory
18. Miami-Erie Canal at Mound Plant
19. Area B Ground Water at Mound Plant
20. Fuel Oil Spill at Sandia National Laboratory, Livermore

21. Navy Landfill at Sandia National Laboratory, Livermore

22. Nonradioactive Dangerous Waste Landfill at Hanford Site

23. Gunnison, Colorado, UMTRA Program Site

24. Rifle, Colorado, UMTRA Program Site

The subprojects are briefly described in Section 4 along with the analytical results of the risk and cost evaluations. A detailed description of each subproject, the assumptions, and analytical results are presented in Appendices A and B.

2. RISK ESTIMATION

2.1 POPULATION RISK MODEL DESCRIPTION

This section discusses the selection of a process for estimating public health risks associated with hazardous waste sites at DOE facilities. Because of the extreme variability in DOE remediation activities and the lack of complete site characterization data, the process must be flexible and capable of providing realistic risk estimates with moderate data requirements. Time constraints negated the possibility of developing new models or making extensive modifications to existing ones. The basic requirements of the risk-estimating process are that it be able to (1) account for a wide range of waste release mechanisms, (2) evaluate the environmental transport of both chemicals and radionuclides, (3) estimate both individual and population risk, (4) quantify risk reduction resulting from remedial intervention, and (5) meet these requirements with limited site characterization data.

2.1.1 Risk Computation Models

A range of models is potentially available to make risk-related decisions relative to environmental restoration activities at sites contaminated with hazardous wastes. Figure 2.1 shows the relationships between different models relative to data requirements and uncertainty in estimated risk levels. The initial decisions about a site can be based on basic risk models that require little prior knowledge of the site. As more information about the site is obtained, more detailed models are typically used in the decision-making process.

2.1.1.1 Screening Models

Screening models are general priority models that can be implemented with general information that is available before any detailed site characterization efforts have been conducted. This class of models often uses a value-based logic system to separate high risk situations from low risk situations. As noted in Figure 2.1, estimates from screening models tend to have the greatest uncertainty. The Hazard Ranking System (HRS) model as promulgated by EPA is an example of this type of model. EPA states that the HRS score is not designed to give real health-based risk information, but instead is used to determine if a site is to be included on the National Priority List (NPL).

2.1.1.2 Ranking Models

Ranking models are priority models that require an intermediate level of site information. These models differ from data-intensive detailed models in that they require less site-specific data and less knowledge of the scenarios to be modeled. Ranking models must incorporate sufficient detail to be capable of a realistic evaluation of the range of situations and problems required by that application. Often the same models can be applied for ranking and detailed analyses.

The Defense Priority Model (DPM) developed by the U.S. Department of Defense (DOD) is a ranking model using value-based logic. However, most ranking models utilize a physics-based approach with potential exposures computed using a transport and uptake model that accounts for constituent, site, and receptor properties.

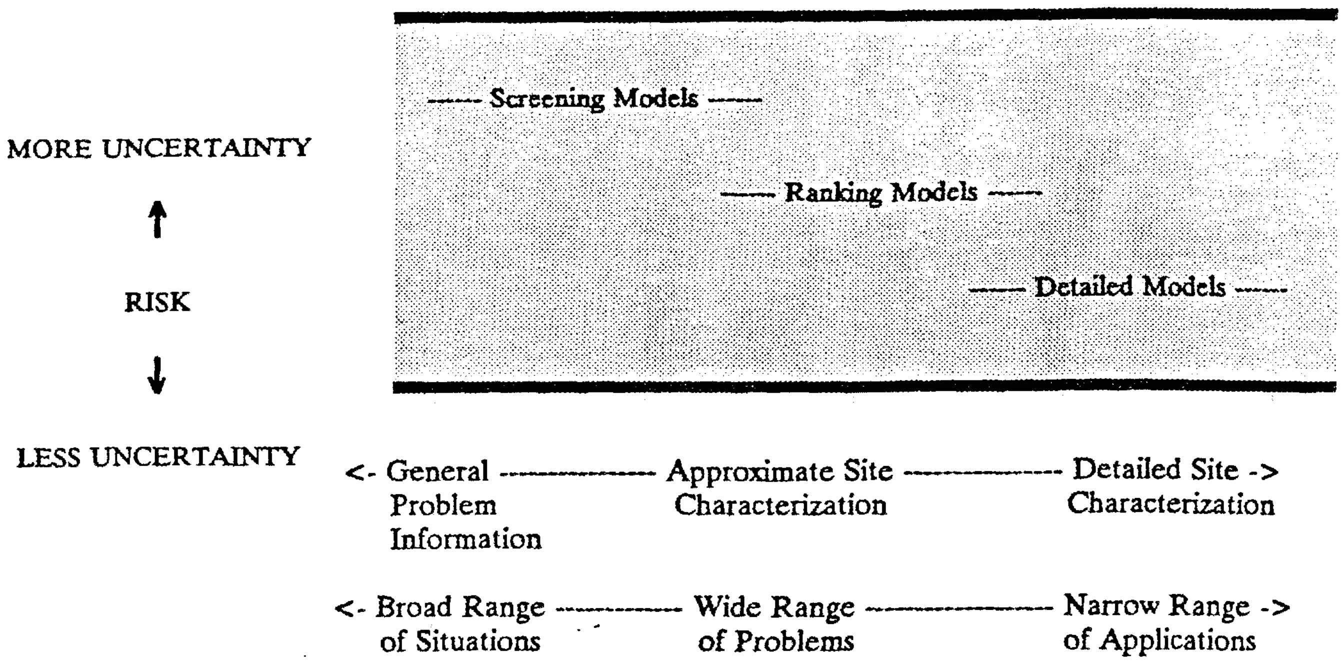

Figure 2.1. Categorization, screening, and detailed risk models.

DOE has developed a ranking level model, the Multimedia Environmental Pollutant Assessment System (MEPAS), for providing input to ranking applications based on public health risk (Droppo et al. 1990). MEPAS is a physics-based exposure pathway computation system that was used in DOE's Environmental Survey (DOE 1988). With MEPAS, approximate risk levels can be computed over a broad range of environmental problems involving different types of contaminants.

2.1.1.3 Detailed Models

Detailed models are models that require extensive site characterization data. Such models tend to focus on site-specific problems. EPA provides models covering a wide range of regulatory issues including the UNIMAP series for air emissions, ground water models (e.g., AT123), nonradioactive exposure assessment models (e.g., GEMS), and radioactive exposure assessment (e.g., AIRDOS). The U.S. Nuclear Regulatory Commission (NRC) provides a similar set of models for evaluating releases from commercial nuclear power plants. DOE has developed several models, including RESRAD, that can be used to evaluate human exposure to radionuclides through various environmental pathways. In addition, many of the major DOE facilities have site-specific models for assessment of public exposures from radioactive material releases.

Although a detailed model can provide the best estimates of risks associated with remediation activities, these models are generally not appropriate for generating risk comparison data over a broad range of problems. First, detailed applications often require data that is not available for many sites. Second, a large number of models would be required to cover the broad range of environmental settings and hazardous waste problems encountered at DOE sites.

2.1.2 Selection of Approach

Given these considerations, the risk team decided that the needs of the pilot study would best be met by a ranking model. Of the ranking models available, MEPAS was judged the best choice for generating the subproject-level risk data in the pilot study. Time constraints negated the possibility of developing new models or making extensive modifications to existing ones. MEPAS was the only physics-based model by which computations could be made over a broad range of environmental problems involving both chemicals and radionuclides. Finally, the environmental transport portions of MEPAS are similar in construction to models recommended by EPA and NRC.

MEPAS had been used earlier by the DOE Office of Environment, Safety and Health during the Environmental Survey Program (DOE 1988) to evaluate and rank environmental problems at 36 installations within DOE. As a result of this program, a large data base of environmental setting and population exposure data was readily available for use in this study. These data had earlier been reviewed by the affected installations. The existence of these data and the past involvement by the installations with MEPAS supported the choice of MEPAS in this pilot study.

2.1.3 MEPAS Application Assumptions

MEPAS is a collection of computer codes designed to quantitatively evaluate (1) release of contaminants from waste units, (2) environmental transport of contaminants to hum,an receptors through air, ground water, surface water, and the food chain, and (3) resulting cancer risk. The computer implementation of MEPAS contains many implicit decisions, such as time discounting of health effects and equivalencies between carcinogenic and toxic chemical risk factors. The short time frame of the study precluded a detailed review of these assumptions by DOE. Instead, the pilot study was conducted within the constraints of the current version of MEPAS, relying on many of the application assumptions used during DOE's Environmental Survey (DOE 1988).

Every effort was made to use site-specific environmental transport parameters during the application of MEPAS. However, site-specific parameters were often unavailable, and generic parameters were used. Exposure scenarios and toxicity parameters provided by MEPAS are believed to reflect current EPA policy and toxicity values. Although the Biological Effect of Ionizing Radiation (BEIR) V report contains the National Academy of Science's most recent risk conversion factors recommended for use in converting low Linear Energy Transfer (LET) radiation doses to risk, the version of MEPAS available at the time of this study uses a risk conversion factor derived by EPA. A federal interagency committee is presently reviewing BEIR V in order to establish a federal consensus for the application of BEIR V recommendations. However, it is not anticipated that their recommendations will differ significantly from the dose to risk conversion factors derived by EPA. Future revisions to MEPAS are expected to utilize the consensus recommendations of the interagency committee.

2.1.3.1 Single Index For Ranking

OMB specified that health risk was to be determined based on risk to members of the general public as well as risk to remedial workers. Both population risk and risk to remedial workers during remedial action are measured in fatalities.

2.1.3.2 Time of Impact

For each constituent, MEPAS provides information on the time of first arrival, time of arrival of peak concentrations, and duration of exposure at the receptor location. MEPAS also provides detailed tables of environmental constituent concentrations as a function of time at the receptor. These parameters described the distribution of contaminant arrival at a receptor.

MEPAS computes major health effects for consecutive average 70-year time periods for a total of 100 time periods (i.e., 7000 years). Seventy years is assumed to represent a typical lifetime of an individual. MEPAS has the option of considering a time-weighting factor that reduces the magnitude of the health impact exponentially with a half-life of 70 years for every 70-year time interval beyond the first time interval.

2.1.3.3 Contaminant Degradation

For this study, the assumption was made that no nonradioactive transformation or degradation of chemical contaminants occurred. In certain situations, the degradation of a chemical may result in a decay product that is more toxic than the parent. MEPAS allows the option of degradation of chemicals and, when rates are known, the degradation of chemicals should be included in future applications when site data on the expected degradation rates are known. Radioactive decay is considered in the MEPAS codes.

2.1.3.4 Worker Dose Computation

In this pilot study, the impacts from occupational exposures were computed separately. Although with minor modifications MEPAS has the capability of evaluating long-term worker exposures, the short time period of the study precluded the use of MEPAS in this capacity.

2.1.3.5 Remediation Activity Risk Assessment

The current version of MEPAS was not designed to be a tool for estimating risks associated with possible remediation activities. Although most cases should be able to be simulated, some limitations are to be expected. Modifications are planned for an upgraded version of MEPAS to facilitate the consideration of remediation efforts.

2.1.3.6 Future Land Use

The analysis in the pilot study assumes that existing conditions will remain static into the future. No allowance is made for future climate, land-use, or population changes.

2.2 WORKER RISK METHODOLOGY

2.2.1 Dose Assessment

With the exception of the no-action alternative, worker exposure may occur while performing tasks associated with remediation alternatives. To assess potential worker exposure, the remedial alternatives were divided into specific activities. For example, a remedial alternative may include excavation, treatment, backfill, and cap. Worker exposure would be estimated according to each task (e.g., excavation).

The primary radiological pathways evaluated in this study were direct radiation and inhalation. Ingestion of contaminants is not considered as dominant a pathway as the previously described pathways for workers, but in some cases may contribute to dose. Chemical exposures were not addressed in this pilot study because it was decided that chemical exposure would not occur once the required health and safety plan was implemented at each site. Fatalities resulting from occupational accidents during general construction operations were included.

2.2.2 Direct Radiation

Direct radiation exposure requires the calculation of worker exposures by taking into account source-to-receptor distances, number and type of shielding materials, and source geometry. Microshield, a microcomputer adaptation of ISOCHLD, is the code used to analyze the shielding of gamma radiation and estimates exposure rates at the receptor (Grove 1988). The code contains 14 source and shielding configurations, with 10 different source geometries.

The source-to-receptor distances will vary among workers and often with remediation task. For the laborers, the source-to-receptor distance was assumed to be 1 meter, unless the activity required closer distances (e.g., handling of drums). Heavy equipment operators source-to-receptor distances were based on equipment type and dimensions, if available, or it was assumed that the operator was located approximately 2 meters from the source, and shielding of ¼-inch-thick steel was also assumed. In some cases, the contribution to the worker exposure was calculated from the contents of backhoe or front end loader buckets. The type of equipment and information given in the site reports were used to estimate the exposure rates.

The number of workers and duration of exposure were multiplied by the calculated exposure rates and by a factor of 0.75 used to convert exposure rate to effective dose-equivalent (Chen 1991, ICRP 51). This product yields the cumulative dose to the workers for the specific alternative.

2.2.3 Inhalation

The inhalation pathway contributes to worker dose, particularly during earth-moving activities. In other cases, inhalation may be a pathway when waste is in particulate form and becomes airborne. A resuspension factor of 0.0005 grams per cubic meter was used to account for the amount of respirable particles that may be airborne during earth-moving activities and assumes dust suppression (e.g., wetting) is occurring (DOE 1986). The breathing rate was assumed to be 20 liters per minute, and the exposure duration is contingent on the project duration for that specific worker. The total radionuclide intake (microcuries) was then multiplied by the effective dose conversion factor to yield worker effective doses. The total number of workers with specific doses was summed to give the inhalation cumulative dose for a remedial alternative.

2.2.4 Risk Assessment

The estimated cumulative doses attributed to direct radiation were multiplied by the life-time low-LET fatal cancer risk factor of 4×10^{-4}/rad (EPA 1989). The inhalation cumulative dose was either multiplied by the low-LET radiation risk factor or by the alpha emitter life-time fatal cancer risk factor of 3.1×10^{-3}/rad (EPA 1989).

Fatalities associated with general construction are also included in the risk estimates for those alternatives that may require construction-type activities. An estimate of general construction fatality was calculated by determining total man-hours per alternative and multiplying by a risk factor of 5×10^{-7}/man-hour (DOE/FMPC 1990).

For cases in which off-site transportation occurs, the driver fatalities were estimated by determining the total number of miles (trip number × miles round-trip) and multiplying by a transportation fatality risk factor of 2.1×10^{-9}/mile (DOE/FMPC 1990).

3. COST ESTIMATION

3.1 COST MODEL DESCRIPTION

3.1.1 Basis of Selection

The nature of this study requires a cost-estimating method with both consistency and flexibility. Consistency is required to ensure that the cost estimates for the alternative can be compared to the others. Flexibility is required to address the broad range of contaminants, remedial technologies, geographic locations, and regulatory frameworks that exist for each subproject. The cost-estimating method used for this study was selected after a careful evaluation of currently available techniques and methods, including a broad range of computer models. This review considered the requirements of this study together with the results of reviews conducted by others addressing topics such as model accuracy and validity.

The need to accurately estimate hazardous waste cleanup costs has led to the development of several computerized cost-estimating tools and models. The development of these tools has been sponsored by EPA, DOE, DOD, and increasingly by private industry. The models in current use were evaluated to determine which best meet the requirements of this study.

The two basic underlying methodologies used for the cost-estimating tools considered for use in this study were detailed methods and parametric approaches. Most of the tools examined use a detailed approach by relying on unit cost data bases for estimating costs. These programs access and extract information from the cost data base and modify the data to create an estimate. Cost modules are built from this process and, when aggregated, form the cost estimate. The programs allow the user to manipulate or modify the cost estimate data base by changing key cost parameters or default values for a site. The models differ in data base complexity and structure, with some offering the user complete access to all unit costs and others offering no access at all.

By contrast, several of the tools rely on the historical costs of previous remediations to build parametric cost relationships. These methods link cost and schedule outcomes using parametric statistical techniques such as correlation, as well as simple and multiple regression. Figure 3.1 underscores that while both estimating approaches start with historical costs, the detailed method uses historical costs to build a unit cost data base. Conversely, with the parametric approach, the expertise for cost-estimating projects is embedded in the models, using formulae to calculate the cost based on the measure of work to be performed.

There are three major classes of waste at DOE sites: hazardous chemical wastes, mixed chemical and radioactive wastes, and radioactive wastes. The selection of a cost-estimating method for this study began with a comprehensive survey of the tools available for application. One of the first requirements was that the tool be capable of analyzing the full spectrum of waste types encountered on DOE environmental projects. Since the majority of the tools examined in this report were built for EPA, only five of the tools have the ability to estimate costs on projects involving mixed or radioactive wastes (common on DOE sites), and three of these are under development. Figure 3.2 organizes the tools by the class of contaminants addressed. Tools listed in Figure 3.2 that are marked with an asterisk are under development and have not been released for full use.

Figure 3.1 summarizes the classification of the tools. Several tools, such as the Removal Cost Management System (RCMS), WET, and LLM, were not selected because they did not produce full cost estimates as output. The HAZRISK model develops an estimate only of the contingency and, furthermore, is undergoing peer review at this time and is not yet available for broad application. Thus, these models were eliminated from further consideration.

This study required the evaluation of sites involving mixed and radioactive waste as well as the need to use a single, consistent approach to all cost estimates. Additionally, this study only considered those models that have been validated or otherwise accepted and released by their authors for use on environmental projects. These requirements eliminated those tools suitable for use only on hazardous waste and those models listed in Figure 3.2 that are marked with an asterisk. The imposition of these criteria identified FAST and COSTPRO as the only models that are both fully developed and flexible enough to evaluate the range of conditions represented by the subprojects chosen for this study.

	UNDERLYING APPROACH		ER APPLICATION		
	Unit cost	Historical	RI and FS	Remedial design and construction	O&M costs
CORA	✓			✓	✓
FAST		✓	✓	✓	✓
HAZRISK		✓	✓	✓	
SCEES	✓		✓		
RACES	✓			✓	✓
M-CACES	✓			✓	
RAAS	✓			✓	
COSTPRO	✓		✓	✓	✓
TRAC-ER	✓		✓	✓	

Figure 3.1. Classification of tools for nonradioactive materials.

	Hazardous chemical waste	Mixed radioactive and chemical waste	Radioactive waste
CORA	✓		
FAST	✓	✓	✓
HAZRISK*	✓	✓	✓
LLM	✓		
M-CACES*	✓		
WET	✓		
RACES*	✓		
RAAS*	✓	✓	✓
RCMS	✓		
SCEES	✓		
COSTPRO	✓	✓	✓
TRAC-ER*	✓	✓	✓

* Under development

Figure 3.2. Classification of tools by contaminants addressed.

COSTPRO is a generic cost-estimating system that can be used to prepare cost estimates on projects from the planning stage through detailed design. The code is a complete PC-based, commercial rewrite of the Los Alamos National Laboratory's mainframe cost-estimating system and, by virtue of its origin, is particularly well adapted to preparing estimates for DOE projects. One of the strengths of the system is its ability to manage up to four different work breakdown structures simultaneously without re-entering the basic cost-estimate takeoff data. This is particularly helpful in instances where multiple format reporting may be required or where reporting requirements are not known in advance or can be expected to change over the life of the project.

The model creates two basic files: (1) a takeoff file, which contains all quantities and direct costs, and (2) a factors file, which contains indirect cost factors, work breakdown structure codes, and estimate notes. Contingency scenarios can be evaluated using a flag to select or delete particular estimate items, allowing consideration of multiple alternatives.

The model has a data base manager that allows the user to build custom data bases and to use data bases created by others such as CACES, which has been established by the Army Corps of Engineers. Data bases can be simple, such as a list of labor rates or bulk material prices, or complex, such as assemblies of labor, material, and equipment required for constructing a monitoring well.

The Freiman Analysis of Systems Techniques (FAST) models are a set of parametric cost-estimating tools oriented towards order-of-magnitude estimating. The models provide a framework for assessing costs when there is limited project design information and few precedents. There are six FAST models, but for environmental restoration projects, the equipment model (FAST-E) and the construction model (FAST-C) are the most appropriate. For operation and maintenance, the Cost-of-Ownership model, FAST-CO, is appropriate. FAST-E is a PC-based equipment-estimating model that uses a combination of seven technology types (electronic, electrical, heat, motion, mechanical control, containment, and support) to characterize a piece of equipment. Performance requirements can be specified (e.g., volume of vessels, length or weight of cable, etc.). The inputs permit the "expression of the fundamental parametric relationships among cost, weight (which can be input or calculated by the model), and technological complexity" in a computerized mathematical equation. For environmental restoration projects, the following may be suitable for analysis by FAST-E: (1) glove-box decontamination and decommissioning projects, (2) the removal of large pieces of equipment, or (3) a cost estimate of process equipment, such as incinerators. FAST-C is a computerized model for calculating the costs, schedules, and risks of all types of civil engineering projects and is currently being converted from a mainframe to PC-based. Complexity values are used to account for the various conditions that cause cost variations. The FAST-C models take into account the following factors: economics, economies of scale, site productivity indices, environmental conditions, operational use of buildings, year of technology, and factor data. Environmental projects that include movement of soils or that involve any structural activities could use the FAST-C model.

The FAST models are flexible, permit effective costing of design as well as connective and support systems, and provide a measure of cost risk appropriate at the preliminary design stage and relevant to conventional construction conditions. The FAST models, however, do not include data on specific cost aspects of projects and must be calibrated by the user based on historical (or estimated) cost of at least one project that is similar to the project the user is estimating. To date, no formal documentation exists on the use of the model for environmental restoration projects.

The cost team for this study has extensive experience working with both FAST and COSTPRO. The FAST models were eliminated from consideration because of the difficulty of using existing cost estimates in the model, a lack of comparable data with which to calibrate the model, and the lack of documentation on the model's applicability to environmental projects. While the open architecture of the model provides the flexibility to address the range of conditions present in this study, the computational nature of the model, which involves proprietary algorithms, would make use of site-specific cost data difficult.

COSTPRO was selected because it not only incorporates the open architecture needed to evaluate the range of waste types and remedial technologies required for this study, but also allows the use of unit cost data and cost relationships for each subproject without sacrificing speed or ease of use.

3.1.2 Cost-estimating Methodology

The first step in developing the cost estimates for this study was the identification of the subprojects to be included. This entailed establishing contact with the appropriate field or project office and requesting documents such as Corrective Measures Studies (CMS) for remediations conducted under the regulatory authority of Resource Conservation Recovery Act (RCRA), Feasibility Studies for remediations conducted under CERCLA, or planning studies prepared for D&D projects. The total body of technical and cost data was then reviewed with regard to the purposes of this study. Technical reports prepared for consideration in the regulatory process often contain cost estimates as part of the alternative evaluation process. In some cases, the cost estimates provided in these documents were summarized and lacked the detail needed for this study, and supporting documentation must be examined. If the technical data lack detail on the scope of alternatives or if fewer than three viable alternatives are identified, additional engineering was necessary. Even when the site had identified three viable alternatives, additional data was required for this study. For example, it was often necessary to prepare a more detailed description of the remedial field work including identification of the field labor levels and exposure conditions so that worker risk could be modeled.

When the information provided by the field included cost estimates, those estimates were reformatted in the COSTPRO system for use in this study. Ideally, this consisted of a simple transcription. A technical review of the data was conducted to verify that the cost estimate was reasonable and complete in areas such as indirect cost, contingencies, and completeness of scope. The objective of this review was to verify that cost estimates used in this study were prepared on a consistent basis to facilitate comparison among estimates. When cost estimates were not available from the field office, estimates were prepared by the cost team.

Cost estimates were prepared using the COSTPRO system for the 24 subprojects in this study, including the no-action alternative and three remedial action alternatives. This system provides the identification of direct costs such as labor, including the impact of personal protective equipment on productivity, labor fringe benefits, and supervision, as well as material costs. The capital cost and operating cost associated with major treatment processes, such as vitrification facilities, were estimated separately. Costs for activities such as treatment or disposal that are paid to off-site contractors were estimated as a unit cost based on the quantity of material involved.

A product-oriented Work Breakdown Structure (WBS) was used to organize the estimate. This facilitated comparison of estimates and reduced estimate preparation and review time. The first level of the WBS is the subproject; each subproject is numbered from 1 to 24 and corresponds to the 24 subprojects identified for this study. The second level of the WBS for this study is the alternative number, which ranges from 0 (the no-action alternative) to 3 (the third remedial action alternative). The third level of the WBS differentiates between construction, and operation and maintenance. Within each of these accounts, such as construction, the work is separated into distinct elements including excavation, transportation, treatment, and disposal. The use of common cost elements within alternatives for a particular subproject allows cost data for activities common to all alternatives, such as surveillance and maintenance, to be entered only once for each subproject. These data were then reused for other alternatives within the subproject when appropriate.

Indirect costs include all activities that cannot be identified with a particular end product such as general and administrative overhead and fee. These costs were usually recovered as a percentage of the direct cost and were displayed separately from direct cost using COSTPRO and described in the estimate criteria.

Other cost elements that were estimated as a percentage of direct cost include escalation and contingency, each of which was tabulated separately in the COSTPRO system. Escalation is an amount added to a cost to represent the cost of the underlying element if purchased at some date in the future. Although the escalation rates used for such calculations are subject to interpretation, a consistent approach was used to escalate these amounts to represent the cost at any particular date. All costs used in this study are stated in 1991 dollars.

Contingency is an amount added to estimates to anticipate potential budget needs for work that was in the scope of the subproject but not covered by the base amount before application of contingency. All cost estimates prepared for this study include a contingency that has been estimated in a consistent, traceable manner following an established methodology. The factors considered when developing contingency include uncertainty in the estimated quantities, economic conditions, uncertainty in unit costs, the potential for design development such as technological refinement, and minor modifications within the scope of the project. Contingency was not used to provide for scope additions, such as additional waste areas, beyond those in the original scope.

Cost estimates prepared for this study estimate contingency using either the CostRisk model or use the contingency assigned by DOE at the Field Office level. The CostRisk model provides for the evaluation of proven risk factors such as design completeness in terms of importance and risk (likelihood of an unfavorable outcome). The results are carried forward to COSTPRO and displayed separately from the cost before contingency.

The cost estimate for each alternative is included in Appendix B of this report. A worker risk table was prepared on the basis of the cost estimate and summarizes the amount of occupational exposure in labor hours together with the conditions under which the worker is exposed. This information is not presented in this report but is used as input to the risk model to calculate exposure of the work-force during remediation.

Whenever possible, the estimates prepared for this study were based on site-specific data developed by DOE. However, design and cost data were not adequate for the purposes of this study in all cases and required augmentation or revision by the cost team. Therefore, in some cases it was necessary to develop new designs and cost estimates solely for the purposes of this study, and, as a result, the cost estimates and alternatives used in this study do not necessarily represent DOE's position on the anticipated cost or preferred approach to remediating a particular subproject.

Quality assurance and quality control were provided for all cost estimates prepared for this study using the procedures and policies contained in the cost team's Quality Assurance (QA) Program. The requirements of this program have been applied to this project using a graded approach that considers the end use of the products being generated. Consistent with the requirement of the QA program, all work was subjected to independent review to verify the traceability of cost estimates, adequacy of supporting documentation, and estimate completeness in terms of the technical requirements of this study. This review applied to all cost estimates prepared for this study but included only limited review of design and cost data prepared by organizations other than the cost team, such as Field Office Contractors. Estimates prepared by the cost team were subjected to additional scrutiny for accuracy and reasonableness. Although evaluation of accuracy and reasonableness were not omitted entirely from reviews of estimates or cost data prepared by others, sufficient information was not available in every case to support such a review.

3.1.3 General Assumptions

This section discusses general assumptions made during cost-estimation, including application of the selected cost-estimating methodology and its impact on the results as a whole.

The cost estimates prepared for subprojects in this study were based on a broad range of information, each unique in nature and varying in both degree of detail and type. Many of the DOE Field Offices are conducting ongoing investigations of these subprojects, and with new information, the design assumptions made for this study could change over time. In some cases, detailed designs and cost estimates were available in a format easily adapted to the needs of this study, including the COSTPRO model. Most subprojects, however, required a considerable engineering effort ranging from preliminary design of a remedial alternative to quantity estimating based on sketches or other information provided by DOE. Those subprojects that lacked complete characterization or design detail often required significant scope related assumptions for the study to proceed. The assumptions made for each cost subproject and each alternative are included in Appendix B with the cost estimates. Cost estimate results are summarized in Section 4.

The most common assumption concerned the quantity of contaminated material to be remediated. Subprojects for which only characterization data were provided required professional judgement to determine the quantity of contaminated material present. When possible, the assumptions regarding the amount of contaminated material made by the DOE Field Offices were used. In other cases, the cost team made assumptions based on professional judgement. The need for three alternatives, regardless of the status of the investigation, required a second common assumption concerning the effectiveness of a particular technology in meeting regulatory requirements. Several of the subprojects selected for this study lacked three alternatives that met regulatory cleanup thresholds, thus requiring development of new alternatives. Some of the technologies assumed to be effective may prove unacceptable in the future. A final cost-estimating assumption concerns the use of unit costs. Every effort was made to use site-specific unit costs whenever available because of the unique conditions encountered on environmental projects. Subprojects with well developed unit cost data were used as sources of data for estimating the cost of other subprojects at the same installation. When no site-specific data were available, representative local data were obtained from in-house sources of the cost team.

The development of an assumed remedial design, including the selection of a remedial technology when none was provided in the subproject documentation, is consistent with the goal of this study because, in all cases, the same design assumptions were used for each remedial alternative examined. Therefore, equivalent scopes were assumed for each alternative considered within each subproject. This process is representative of the alternative identification phase that occurs at the beginning of an ER subproject when alternatives are screened before sufficient information is available with which to determine the exact scope of the work.

4. SUMMARY OF RESULTS

This section presents short descriptions of each subproject and summarizes the analytical results of the study. Detailed information concerning the results and how each subproject was modeled can be found in Appendices A and B.

Short descriptions of all the subproject sites are followed by summary data tables. Table 4.1 summarizes the human health and cost data for each of the 24 subprojects and their remedial alternatives. Columns 3 and 4 of Table 4.1 show the expected number of fatalities among members of the general public and remedial workers, respectively. Column 5 shows the risk to a reasonably exposed individual. Table 4.2 presents a ranking of the 24 subprojects by population baseline risk. Table 4.3 presents a ranking of the 24 subprojects by dollar cost per reduced fatality using the most cost-effective alternative from each subproject.

The health risk and cost estimates presented in the tables should be viewed as rough estimates with a large degree of uncertainty. The risk estimate based on pre-remedial investigation (RI) data can vary by as much as 3-4 orders of magnitude from those developed at the completion of an RI. This uncertainty could be quantified by varying the parameters that are not well defined through their potential ranges. A computer run would be conducted as each parameter is varied. The next step in the process could be to determine this uncertainty. The health risk numbers as presently constituted should not be used to distinguish differential risk between specific sites, but rather to make broad site groupings with respect to risk.

As discussed in Section 2, MEPAS can calculate risk by discounting future fatalities or by considering a future fatality as equal to a present fatality. However, MEPAS is designed to calculate risk for 100 consecutive 70-year periods (i.e., 7,000 years) rather than the 10,000 year time period currently used in performance assessments stipulated by DOE policy. MEPAS is capable of producing both discounted and non-discounted future fatalities. Presentation of both discounted and non-discounted future fatalities allows a comparison of the effects of this decision on the data (Table 4.4).

Baseline risk assessments, conducted either in association with the RI/FS or prepared for other purposes, have been performed at nine of the 24 sites. However, most of the studies only estimate individual risk. Table 4.5 presents a comparison of individual risk as computed by MEPAS with other independent risk assessments. An analysis of the individual risk assessments indicates that most of the differences between MEPAS and the RI/FS can be attributed to differences in assumed exposure scenarios. When applied to well characterized sites, MEPAS appears to produce results similar to those obtained during the RI/FS risk assessment process.

4.1 SITE DESCRIPTIONS

The following are short descriptions of each subproject site. Remedial alternatives are described in Appendices A and B.

1. Fernald: Fernald Environmental Management Project (FEMP) Operable Unit 1 (OU1)

Four clay-lined and two rubber-lined waste pits served as repositories for process wastes and construction rubble. Adjacent to the waste pits, a burn pit was used for disposal of chemicals and other combustible wastes. In the same area, a clearwell operated as a settling basin for process wastes and storm water runoff. These eight waste disposal units occupy about 38 acres of the FEMP site and are labeled collectively as Operable Unit 1 (OU1).

The waste pits of OU1 vary in depth from 13-30 feet. Compacted native clay lines the walls of Pits 1, 2, 3, and 4. Rubberized elastomeric membranes serve as liners in Pits 5 and 6. Although the pits are no longer in use, they contain such wastes as uranium, thorium, construction rubble, fly ash, and various other wastes as a result of past waste disposal practices. Pits 3 and 5 are referred to as "wet" because they received mostly waste in slurry form. Pits 1, 2, 4, and 6 are referred to as "dry" because they received mostly dry solid waste from trucks. The pits are a potential source of uranium, sulfate, barium, chromium, and other chemical contamination of ground water in the western and southern areas on- and off-site. The area covering Pits 1, 2, 3, and the burn pit is not graded to allow all stormwater drainage to be directed to the clearwell, thereby causing runoff to enter a nearby creek, Paddy's Run. This creek has been identified as a source of downward migration of pollutants into the sand and gravel aquifer. Pits 1, 2, 3, and the burn pit are potential sources of uranium, thorium, nitrates, sulfates, and organic contaminants. In addition to these wastes, Pit 4 contains a substantial quantity of barium. For this reason, the waste in Pit 4 is classified as a Resource Conservation and Recovery Act (RCRA) mixed waste. This pit is currently covered with an interim RCRA cap. Pits 5 and 6 are uncovered and retain standing water at the pit surfaces. During the summer months, portions of Pits 5 and 6 dry out, subjecting the surface to wind erosion. The rubberized lining of Pit 5 has torn, and lining joints have failed. Pollutants from this pit may be entering the ground water beneath the pit and contributing to elevated levels of contaminants detected in the water below the pits. Pits 5 and 6 may have received barium-containing materials from Pit 4 through the practice of pumping accumulated ground water on top of Pit 4 to Pits 5 and 6 via a portable pump.

2. Fernald: Fernald Environmental Management Project (FEMP) Operable Unit 4 (OU4)

Four concrete silos were built on the western edge of the site to store pitchblende processing wastes. Silos 1 and 2 received waste in slurry form, whereas Silo 3 received only dry waste. Silo 4 was never used. Operable Unit 4 (OU4) consists of the two K-65 silos (Silos 1 and 2), the metal oxide silo (Silo 3), the soil berms surrounding Silos 1 and 2, and the soils directly beneath the silos. The silos contain high levels of uranium and its decay products, including radium-226 and radon gas.

Silos 1 and 2 are 80 feet in diameter, 36 feet high to the center of the silo dome, and 27 feet high to the top of the vertical walls. The walls are 8-inch-thick concrete, as are the outer part of the domes, which taper to 4 inches in thickness at the center. The floors of Silos 1 and 2 consist of 4 inches of concrete over an underdrain system. Corrective actions performed to maintain the integrity of Silos 1 and 2 include repairing the walls and surrounding the silos with an earthen embankment referred to as a silo berm. Protective covers of steel and plywood were placed over the dome centers after an assessment in 1985 deemed the original structures unsound.

In 1987, a 3-inch layer of polyurethane foam and a 45-mm waterproof coating were placed over the domes. Silos 1 and 2 are used for the storage of radium-bearing residues formed as by-products of pitchblende ore processing. Silos 1 and 2 received slurried process wastes from 1952 to 1958. Solids in the radioactive slurry settled, and the liquid waste was decanted through valves placed at various heights along the silo walls. As the level of solid waste approached the nearest valve, the valve was sealed and the next higher valved opened. Settling and decanting continued in this way until the silos were filled to about 4 feet below the top of the vertical wall. The primary radioactive contaminants in Silos 1 and 2 are radium-226, lead-210, natural uranium, and thorium-230. Nonradioactive lead is also abundant. Above the waste residues, Silos 1 and 2 contain an air space in which radon produced from the decay of radium-226 accumulates. This radioactive gas diffuses through the silo walls. Because the silo berm retards diffusion of the short-lived radon, it accumulates the daughter products of radon decay, including lead-210 and polonium-210.

Process wastes spray calcined into a dry powder were blown under pressure into Silo 3. Silos 3 and 4 did not require corrective actions. Silo 3 contains primarily thorium-230, silica, radium-226, natural uranium, and other oxides. It is a less significant radon source because it contains lower levels of radium.

3. Lawrence Livermore National Laboratory (LLNL): Site 300, Landfill 6

Landfill 6, or Pit 6, is a closed landfill in the southwestern portion of Site 300 approximately 100 feet from Site 300's southern boundary. It is roughly square in shape and approximately 103,000 square feet (2.4 acres). It was established in 1964 and, as was typical at that time, was unlined and without containment structures, or leachate detection, collection, or removal systems. It received a variety of wastes from the LLNL main site and Lawrence Berkeley Laboratory between July 1, 1964, and February 20, 1973. Materials were deposited in only three parallel trenches within the landfill area and in six smaller trenches in the northern tier of the landfill. Together, these trenches account for 13% of the total landfill area, approximately 13,000 square feet. When the landfill closed in 1973, it was covered with approximately 3 feet of native soil. It has subsequently been developed as a rifle range used by LLNL Safeguards and Security Department as well as by San Joaquin County Police Department. A moderately steep hillside lies north of the pit, and a deep gully lies west. Man-made earth berms have been constructed that partially enclose the rifle range along its south, east, and southeastern borders. The rifle range is partially covered by a metal canopy, and electrical lines have been installed in the canopy area.

Although no specific information about the waste deposited in Pit 6 is available, it is known to contain construction materials, laboratory equipment and chemicals, scrap metal, paint wastes, electrical parts, and the remains of biomedical research animals. It is suspected that polychlorinated biphenyl (PCB) dielectric fluids are contained in over 2000 electrical capacitors in the pit. In addition, it is suspected that compressed gas cylinders of unknown content and unspecified waste possibly contaminated with beryllium and mercury are also present.

4. Lawrence Livermore National Laboratory (LLNL): Site 300, Building 834 Complex

Building 834 Complex is on a hilltop in the eastern portion of Site 300. Steep hillsides and gullies lie to the north and south of the complex. Man-made earth berms have been constructed immediately adjacent to the complex buildings. Much of the immediate area is covered with asphalt.

Building 834 Complex supports Site 300's physical-, environmental-, and dynamic-testing program, which requires the use of trichloroethylene (TCE) as a heat transfer fluid during temperature experimentation. TCE is pumped through aboveground pipes to test cells around the perimeter of the complex. The radius from the pumping stations to the test cells is about 130 feet. Some of the materials used in the pump seals, valve gaskets, and pipe thread seals were partially dissolved by TCE causing leaks in the pumping-station buildings and near the valve systems outside the pumping-station buildings and test cells. Spills inside these buildings were washed into floor sumps that drained into the septic system. The septic system leach field is another known area of volatile organic compounds (VOC) release. Released chemicals have been contained almost exclusively within 80 feet of the ground surface.

5. Savannah River Plant: F & H Area Seepage Basins

The F Area Seepage Basins routinely received wastewater containing low-level radioactivity and chemicals from the F Area separations facilities. These basins use the soil column and ground water pathway to surface outcrops to delay the release of tritium into surface streams and effectively retain other radionuclides. The H Area Seepage Basins received wastewater containing low-level radioactivity and chemicals from the H Area separations facilities.

Because both area basins started operation in 1955, received the same types of waste, and are located in the same general area, the F Area and the H Area Basins were combined to form the F & H Area Seepage Basins. Both the F and H systems consist of three F and four H basins connected in series; combined, these basins received an average influent of approximately 110×10^6 gallons per year. All basins have been closed under RCRA.

The F&H Area Seepage Basins were designed and operated to allow wastewater to percolate through the soil at the sides and bottoms. The seepage eventually entered the ground water, cropped out, and entered tributary streams that eventually entered the Savannah River. Ground water contamination associated with both sites consists primarily of tritium, sodium, and nitrates, with occasional elevated levels of mercury, manganese, cadmium, and lead. Primary sources of effluent being sent to the basins are the nitric acid recovery unit overheads, general purpose evaporator overheads, and the overheads from the two waste tank farm evaporators. Other sources of effluent were cooling water from the tritium facilities, retention basin transfers, and liquids from receiving basins for off-site fuel. Soil samples taken over the area indicate both radioactive and nonradioactive constituents in the basin sediments.

6. Savannah River Plant: New TNX Seepage Basin

The New TNX Seepage Basin located in the 300-square mile Savannah River Plant received wastewater generated by the TNX facilities. The New TNX Seepage Basin began operation in 1980 when it was constructed to replace the old seepage basin. The basin continued operation until 1988 when discharges to the New TNX Seepage Basin were rerouted to the TNX Effluent Treatment Facility (ETF). The waste discharged into the basin consisted of nonhazardous wastewater from pilot-scale simulation conducted out of the TNX facility. From 1983 to 1988, the majority of the wastewater sent to the basin contained simulated, nonradioactive sludge and other laboratory chemicals.

The New TNX Seepage Basin consisted of two rectangular sections: an inlet section and a seepage section. The two sections have surface dimensions of approximately 50 feet and 75 feet (inlet) and 60 feet × 250 feet (seepage). Both sections are approximately 10 feet deep and are connected by an underground 8-inch-diameter vitrified clay pipe. The volume of the two sections combined is approximately 1 million gallons (5,000 cubic yards).

7. Savannah River Plant: M Area Settling Basin

The M Area Settling Basin, located on the Savannah River Site (SRS), is approximately 1.8 km from the nearest plant boundary. From 1954 to 1958, M Area effluent was discharged via a process line to Tims Branch, a tributary to Upper Three Runs Creek. In 1958, the Settling Basin was constructed to retain uranium and metals discharged in the effluent. The basin has routinely received wastewater containing extruded enriched uranium-aluminum alloy fuel, aluminum-canned depleted uranium metal targets, other metals, acids, and caustics from three production facilities and two support laboratories in the M Area. The purpose of this basin was to restrict the transport of enriched uranium by settling out and containing the uranium. A significant amount of the wastewater discharged to the seepage basin overflowed into a ditch that transported them to a seepage area and Lost Lake. Approximately 50% of the liquid that overflowed from the basin seeped into the ground in this 3-acre seepage area. The basin is currently closed; discharge to the basin was stopped on July 16, 1985.

Ground water contamination associated with the site consists primarily of tritium, nitrates, 1,1,1-trichloroethane, carbon tetrachloride, nitric acid, tetrachloroethylene, and trichloroethylene. Primary sources of effluent being sent to the basin can be characterized as electroplating waste from aluminum forming and metal finishing processes. Soil samples taken over the area indicate both radioactive and nonradioactive constituents in the basin sediments.

8. Savannah River Plant: Sanitary Landfill

Operations at the Sanitary Waste Landfill used at the Savannah River Site (SRS) originated in 1974. In 1986, the State of South Carolina Department of Health and Environmental Control (SCDHEC) approved an expansion of the original 32-acre tract to include a 16-acre northern expansion and a 22-acre southern expansion. In 1987, the southern expansion began receiving waste and is presently nearing capacity. By midyear of 1992, operations will begin at the northern expansion.

The landfill is a trench and fill operation. Currently, the landfill receives 15,000-20,000 tons of waste (approximately 70,000 cubic yards) per year. Waste is placed in excavated trenches that are typically 50 feet wide, 500 feet long, and 15 feet deep. Materials such as paper, plastics, cafeteria garbage, rubber, wood, cardboard, empty cans, and discarded office furniture are deposited in the trenches and covered daily with a thin soil blanket. Also, separate trenches are used for the burial of asbestos and sludge. The asbestos trenches receives asbestos materials and construction rubble. Skimmings from the sewage treatment plant and dead animals are placed in the sludge trench. Once a trench is full, approximately 3 feet of topsoil caps the complete trench.

On January 26, 1990, DOE notified SCDHEC that rags and wipes used with F listed solvents for cleaning and radioactive decontamination had been deposited in portions of the Sanitary Waste Landfill. In response, SCDHEC advised SRS that the F listed solvent rags and wipes constituted hazardous waste subject to RCRA regulation. Presently, DOE and SCDHEC are negotiating an agreement that includes a RCRA closure for those portions of the sanitary landfill that received solvent rags and wipes.

9. Oak Ridge National Laboratory (ORNL): Waste Area Grouping (WAG) 6

Waste Area Grouping (WAG) 6 borders White Oak Lake near White Oak Dam and State Highway 95. WAG 6 consists of three solid waste management units: Solid Waste Storage Area 6 (SWSA 6), the Emergency Waste Basin (EWB), and the Explosives Detonation Trench (EDT). While both SWSA 6 and EDT have received a variety of wastes, EWB has reportedly never been used and, therefore, will not be included in the risk assessment.

SWSA 6 contains more than 1000 trenches and auger holes. Trenches are assigned to one of the following categories depending upon the waste placed in them: (1) high activity, (2) low activity, (3) biological, (4) asbestos, (5) baled, (6) fissile, (7) high-activity concrete lined, and (8) low-activity concrete lined. Dimensions of trenches were highly variable depending on topography and trench type, but they generally were approximately 50 feet long × 10 feet wide × 13-20 feet deep. Auger holes have been classified as one of three types, depending upon their waste content: (1) high-activity, (2) solvent, or (3) fissile. The auger holes, which measured from about 1-4 feet in diameter and 20 feet in depth, were placed in higher elevation areas. Containers as large as 55-gallon drums were placed in the auger holes, which were generally spaced about 3 feet apart.

Until May 1986, all trenches and most auger holes were unlined. Since that time, all disposal of radioactive waste has been in concrete silos. No chemically hazardous wastes have been disposed in SWSA 6 since April 1986. The EDT was used to detonate explosives and shock-sensitive chemicals, with debris from the explosion remaining in the trench. The trench is a potential source of ground water contamination through contaminant leaching.

10. Y-12 Plant: Bear Creek Operable Unit 4 (OU4)

While Bear Creek Operable Unit 4 (OU4) is not a Solid Waste Management Unit (SWMU) in terms of a strict RCRA definition, contaminants in floodplain soils represent a potential source of continuing, uncontrolled releases to the environment. A number of SWMUs are suspected to have contributed to contamination in Bear Creek. These include the S-3 Ponds, the Oil Retention Ponds, the Oil Landfarm, Bear Creek Burial Grounds, Sanitary Landfill I, Rust Spoil Area, Spoil Area I, and the Hazardous Chemical Disposal Area-Burnyard/Boneyard, as well as the White Wing Scrap Yard (an Oak Ridge National Lab site that is located in the Bear Creek Watershed). In spite of the quantities and varieties of contaminants known to have been disposed of in the SWMUs, very few contaminants have been detected in Bear Creek surface water, sediment, or floodplain soils at concentrations warranting human health or ecological concern. The chief contaminants and respective media of concern are polychlorinated biphenyl compounds (PCBs) and uranium in floodplain soils, PCBs in sediment and biota, and nitrate, aluminum, uranium, and cadmium in surface waters. Volatile organic compounds (mainly industrial solvents such as trichloroethene and tetrachloroethene) occur in ground water and certain tributaries at concentrations warranting human health concern, but there is a near absence of these compounds in mainstream Bear Creek, and the ground water plumes are restricted to the immediate area of the SWMUs.

11. K-25 Plant: Pond Waste Management Project

From February 1987 through September 1988, waste sludge removed from a retention basin and a holding pond was collected and stored in drums at the K-1417 Drum Storage Yard site. The 78,000 drums sit on a 1335 feet × 280 feet asphalt pad located near the Mitchell Branch Stream. Approximately 45,000 of these drums contain sludge stabilized in a concrete grout, although some of the stabilized drums contain free liquid as well. About 32,000 drums house raw sludge. Eight thousand drums have been drained of free liquid and moved to on-site indoor storage. The sludge stored in the drums contains various inorganic, organic, and radioactive wastes; hence, it is a RCRA mixed waste. The drums were designed for temporary storage, and inspections have revealed leaks in the drums.

The K-1417 drums show external signs of internal corrosion. Liquid sludge is leaking from the drums onto the asphalt pad and possibly into the surrounding soils. Solid sludge may also be escaping from the 89- and 96-gallon drums. The grout-stabilized drums containing no free liquid are not thought to contribute to contaminant release.

12. Y-12 Plant: Building 9201-4 (Alpha 4) D&D

The 9201-4 (Alpha 4) facility, which was shut down in 1962 and remained on controlled stand-by until 1983, contained equipment associated with the colex solvent extraction process. The process utilized a lithium hydroxide feed stream and involved the use of large quantities of mercury as a solvent. While only low levels of mercury (below 2 μg/L) can actually dissolve in ground water as it moves through contaminated areas, ground water is considered a contaminant pathway in areas where ground water enters basements and drains. The increased flow rate in such open spaces allows the water to serve as a transport mechanism for moving contaminated soil into surface streams, where the contamination becomes a surface water and sediment problem. Mercury can also be released to surface waters by the discharge of water from building drains and storm sewers, as well as by overland transport.

13. Argonne National Laboratory (ANL) East: 800 Area Landfill and French Drain

The 800 Area Landfill (LF) is an active on-site sanitary landfill that is used to dispose of most of ANL-East's nonradioactive solid waste products. The site is located on 21.78 acres at the extreme western edge of the ANL-East site and is surrounded by the Waterfall Glen Nature Preserve on three sides. The LF is approximately 600 feet × 900 feet and is underlain with a natural deposit of low permeable silty clay glacial till; however, no engineered liner exists under the landfill. The LF was constructed in 1966 and was first used in 1968. It has been operating under permit from the Illinois Environmental Protection Agency (IEPA) since 1981; a RCRA Part B Permit application is currently being prepared. Remediation of this site may occur under RCRA as a condition of this Part B Permit, under CERCLA, or under the IEPA's voluntary cleanup program. The expected remaining useful life of the landfill is 13 years based on current waste generation rates.

Before 1981, waste disposal in the LF was uncontrolled and largely undocumented. It is likely that the LF was used for the disposal of both chemical and radioactive wastes in several areas of the LF. A vertical french drain, approximately 10 feet × 10 feet and located in the extreme northeast corner of the LF, was used from 1969 to 1978 to dispose of approximately

29,000 gallons of nonradioactive hazardous wastes, including various organics, waste oil, diesel fuel, kerosene, and PCB-contaminated fluids. The french drain area of the LF was clay-capped in 1979; no wastes were removed. Other smaller french drains at other locations in the LF may have used prior to 1981. The presence of low levels of tritium in some of the LF monitoring wells indicates that radioactive waste may have been disposed in the LF. The LF is also used for the disposal of asbestos from on-site demolition and reconstruction projects. The annual amount of asbestos disposed in the LF fluctuates, ranging from 615 cubic feet in 1984 to 2000 cubic feet for 5 months in 1987. Asbestos disposal is expected to increase in the next few years.

The 800 Area Landfill is located approximately 0.27 mile from commercial/industrial facilities, 0.01 mile from wetlands located in the Waterfall Glen Nature Preserve, 0.25 mile from agricultural lands, and 0.3 mile from the nearest residence. Demographic assessments of the site show 3300 persons within a 1-mile radius, 12,700 persons within a 2-mile radius, and 39,600 within a 3-mile radius.

14. Argonne National Laboratory (ANL), East: 570 Holding Pond

The 570 Holding Pond is an empty unlined lagoon, originally 100 feet × 75 feet, that has been inactive since 1980. The 570 Holding Pond is also referred to as a settling pond, the WWTP (wastewater treatment plant) earthen lagoon, and the overflow pond. The pond is located on the eastern side of ANL-East in the northeastern portion of the wastewater treatment plant. According to ANL-East internal memoranda, the original purpose of the 570 Holding Pond was to act as a temporary holding area for suspect radioactive wastewater. Water diverted to the pond from the laboratory drain system would be monitored for radioactivity. Depending on the results of the monitoring, the water would either be released to Sawmill Creek via an outflow and drainage swale, or processed. No records exist to indicate how frequently the pond was used.

Monitoring conducted in the area of the pond in the early 1960s showed elevated levels of alphas, beta, and uranium in the soil. Additional monitoring during the 1970s showed low levels of plutonium-239. Small quantities of hazardous chemicals may also be present in the pond from laboratory wastewater. Although the lagoon was removed from service in 1980, the potential remains for Sawmill Creek contamination and ground water contamination through migration of contaminants from the lagoon soil. The site is not well characterized, but site personnel suspect primary contamination from metals and radionuclides and possibly PCBs.

15. Argonne National Laboratory (ANL), West: Liquid Waste Process Area

The Liquid Waste Process Area is located inside Building 752 at ANL-West and has been declared a Decontamination and Decommissioning (D&D) area. Building 752 is the Laboratory and Office (L&O) and support area at ANL-West. When it was operable, the evaporator system, a tube and bundle evaporator, was fed steam through one side of the bundle, and solids were drawn off the bottom of the evaporator. The liquid discharge of the low-level radioactive waste was then collected, recondensed, run through ionexchangers and disposed to the environment via a series of underground pipes that led to a leaching pit to the southwest of Building 752. The piping leading to this leaching pit has been capped and abandoned in place. The site was decontaminated and decommissioned because workers were exposed to potential radiation while they changed the bundles in the evaporator. Moreover, a new facility was built, which is a shielded hot air drum evaporation process, making the evaporator in Building 752 obsolete. This new facility is located in Building 798, about 600 feet north of Building 752. The Liquid Waste Process Area is on standby for disposition of the evaporator, which has not been in use since May 1983.

16. Idaho National Engineering Laboratory (INEL): BORAX-V

The BORAX-V D&D Facility is managed by EG&G Idaho and consists of the inactive BORAX, or Boiling Water Reactor Experiment, area. BORAX-V is located in the southwestern section of the INEL and occupies 6 acres, including the leach pond and BORAX-I contaminated area. The BORAX facility was originally developed in 1953 as BORAX-I, to test the ability of an open-top boiling water reactor to protect itself against sudden increases in reactivity. The last test of BORAX-I was in 1954 when the reactor was intentionally destroyed. After its destruction, the reactor was buried in place and the site was cleared and abandoned. A new site, 100 yards northeast of BORAX-I, was chosen for subsequent BORAX testing. The BORAX-II through V experiments were conducted from 1954 to 1964 in a reactor housed in one of two main buildings. They were designed to test various aspects of boiling water reactors. This facility has been decontaminated and decommissioned and has been inactive for the past 30 years.

The two structures considered at the D&D BORAX-V site are the Reactor Building and the Turbine Building. The Turbine Building was decontaminated and decommissioned in 1991, and the building has been gutted. The Reactor Building has had the radioactive fuel and other components removed, but still has components left that need to be disposed of to finish the D&D on the building. For the purposes of this study, only the Reactor Building will be modeled since the Turbine Building's components are no longer present. Sampling data from the Reactor Building show that the primary constituents of concern are Cobalt-60 and Cesium-137. In the previous work done on the Reactor Building, the aboveground portion of the building was removed and the underground portion covered by a concrete slab and temporary roof; thus access is extremely limited.

17. Los Alamos National Laboratory: Los Alamos Power Reactor Experiment (LAPRE) Reactor II

The first Los Alamos Power Reactor Experiment (LAPRE) reactor was disassembled between 1956-1958. The LAPRE Reactor II was subsequently built as a replacement reactor and is located in Technical Area 35 (TA-35). The LAPRE Reactor II, when it was operable, was fueled by uranium-235 in a 95% pure phosphoric acid solution. The reactor vessel is only 4.5 feet long and 15 inches in diameter. It has a fuel reservoir tank and an additional reservoir tank, both of which are buried along with the reactor vessel at a depth of 12-16 feet. These "tanks" are about 15 feet long, 8 inches in diameter, and are housed in a corregated metal pipe. The reactor itself is housed in a 48-inch steel safety enclosure. The LAPRE Reactor II was built in 1959, shutdown in 1960, and then decontaminated and decommissioned (D&D). The LAPRE Reactor II was decommissioned because some of the casings of the reactor are made of reclaimable gold and because it is a surplus facility.

18. Mound: Miami-Erie Canal

Built to serve as a waterway transportation route and abandoned in 1915, the Miami-Erie Canal lies immediately west of the Mound Plant boundary. Today, the 2,133-meter-long depression that remains serves as a drainage pathway for surface water runoff to the Great Miami

River. A concrete dam with a one-way "flapper" valve separates the canal into northern and southern halves. The north canal is a 40-feet-wide grassy ditch that fills partially with water during precipitation. This water may drain to the south canal through the flapper valve. The southern portion of the canal is heavily vegetated, yet supports a light year-round surface water flow. The south canal receives discharge from the National Pollution Discharge Elimination System outfall. A 20-feet-wide overflow creek conveys surface water from the canal to the Great Miami River. Limited sampling efforts indicate that canal sediments contain above background levels of tritium and plutonium-238.

Until 1970, the Miami-Erie Canal received tritium-containing discharge from the Mound Plant site drainage ditch. In 1976, the inventory of tritium in the canal was estimated as 200 curies, with a half-life of approximately 3 years. Because the nature and extent of tritium contamination in the canal is poorly understood, the transport of tritium from this site is not addressed at this time.

The rupture of an underground liquid waste pipeline in 1969 discharged plutonium nitrate into the soil of the pipeline area. The soil particles, contaminated with strongly bound plutonium-238, were suspended in moving rainwater after precipitation at the site. Normal sedimentation processes deposited the contaminated soil in the Miami-Erie Canal. The Environmental Survey Preliminary Report estimates that about 5.2 curies of plutonium-238 were deposited in waterways off the site. As a result of natural drainage patterns, the contamination has been buried by up to 3 feet of sediment.

19. Mound: Area B Ground Water

From 1948 to 1977, the 4-acre area known as Area B served as a waste disposal area. The rectangular Area B lies midway between the northern and southern site boundaries and only a short distance from the western edge of the site.

Area B served as a waste disposal area from 1948 to 1977. No records of the quantities of wastes disposed in the Area B landfill were kept. However, it is known that the area received paper, glass, wood, kitchen garbage, and laboratory and office wastes. Drums contaminated with thorium, and sand contaminated with polonium, were also buried or placed in Area B. In 1977 and 1978, much of the waste in the historic landfill was excavated and placed in a new sanitary landfill located in the southern half of Area B. An overflow pond was constructed in the excavated area.

The ground water beneath Area B is contaminated with volatile and semivolatile organic compounds and various radionuclides. Although the historic landfill is the suspected source of contamination, the presence of many wells in and around Area B may cause a local ground water depression such that a pre-existing ground water contaminant plume is drawn under Area B.

20. Sandia National Laboratory (SNL), Livermore: Fuel Oil Spill

The Fuel Oil Spill site is located near the center of the SNL installation and is a 179,900-gallon-aboveground fuel reserve storage tank. Number 2 diesel fuel oil was released from the storage tank in February 1975 when an underground transfer line buried 4 feet underground was accidentally punctured. The spill occurred 75 feet north of the storage tank. The exact amount of diesel fuel lost is not known but is estimated at 59,000 gallons. A small portion of fuel was recovered from the shallow light pole trench near the puncture but the exact amount recovered was not reported. The fuel has contaminated the unsaturated zone to the water table and is considered a potential source of ground water contamination.

21. Sandia National Laboratory (SNL), Livermore: Navy Landfill

The Navy Landfill is located in the southern portion of SNL. This area was once part of a natural ravine extending 200 feet × 400 feet. The site currently consists of debris fill in and around the ravine. Landfill operations were begun by the U.S. Navy in 1942 and continued until 1947. Disposal at the site was resumed by Lawrence Livermore National Laboratory (LNLL) in 1952 and continued until SNL requested, in 1960, that disposal practices at the Navy Landfill cease. Since that time SNL has used the site as a high-explosive storage magazine area. The area is now used to store small arms ammunition, weapons components, solid rocket propellant and unspecified classified explosive materials and components.

The Navy Landfill was not an engineered structure and was, therefore, not provided with a liner, cover, or other means for containment, leachate diversion, or surface drainage control. Refuse was deposited at the site on unprotected ground. Trash, construction debris, and soil were disposed of in the ravine by the Navy. LLNL also disposed of construction debris at the site along with empty containers without reference to the original contents or use of these containers. The Navy Landfill now contains less than 1 million pounds of non-decomposable inert solid waste. Landfill operations ceased in 1960, but no formal closure of the site was instituted. Construction debris, including concrete slabs, machine turnings, wire, and plastic are visible at the surface of the landfill.

22. Hanford Reservation: Nonradioactive Dangerous Waste Landfill (NRDWL)

The Nonradioactive Dangerous Waste Landfill (NRDWL) opened in 1975 and received waste until 1985. It is located in roughly the center of the Hanford reservation and is adjacent to the Solid Waste Landfill (SWL). Together, NRDWL and SWL occupy 76 acres. NRDWL is composed of trenches each measuring 400 feet × 46 feet at their surface. When the landfill ceased receiving waste, six of the trenches contained packaged chemical waste, and nine trenches contained asbestos waste. The remaining three trenches and unused portions of two others are empty. Trenches containing waste have been covered with 6-10 feet of excavated soil. Chemical waste in the six trenches was buried in containers, primarily 55-gallon drums; all liquid waste is packed with absorbent material. Most trenches contain a single row of drums, although at times it was necessary to stack them one on top of another. A wide variety of chemical waste has been buried in the landfill, including laboratory chemical waste, paint, oil, and solvents. Up to 2700 different types of chemical waste have been identified. There is no evidence of contaminant release from NRDWL.

23. Uranium Mill Tailings Remedial Action (UMTRA) Site: Gunnison, Colorado

The Gunnison UMTRA site is an inactive uranium mill tailings site on the south edge of Gunnison, in Gunnison County, west-central Colorado. The site is in a wide mountain valley of the Gunnison River and Tomichi Creek and on the west slope of the Rocky Mountains. The mill was operated by the Gunnison Mining Company from February 1958 until December 21, 1961, when Gunnison Mining Company merged with Kermac Nuclear Fuels Corporation, a wholly owned subsidiary of Kerr-McGee Oil Industries, which became the surviving company. Kermac operated the mill until it closed in April 1962. All uranium produced was sold to the United States Atomic Energy Commission. About 540,000 tons of ore were processed by acid leaching. On December 28, 1964, Kermac Nuclear Fuels Corporation sold the entire millsite to Colorado Ventures, Inc., who subsequently deeded 3.5 acres at the north end of the original 65 acres to Gunnison County in December 1966 for airport expansion. In August 1973, Colorado Ventures sold the property to The Mill, a limited partnership, its current owner.

Contaminated materials at the Gunnison processing site include one almost rectangular tailings pile covering about 35 acres to an average depth of 9 feet and containing about 459,000 cubic yards of tailings, subsurface contamination, windblown contamination, ground water contamination, and miscellaneous areas that have been contaminated by uranium processing activities. The total volume of contaminated materials is estimated at 718,900 cubic yards.

24. Uranium Mill Tailings Remedial Action (UMTRA) Site: Rifle, Colorado

The Rifle UMTRA site consists of two separate, inactive uranium mill tailings sites outside Rifle, in Garfield County, west-central Colorado. The eastern site is known as Old Rifle and is approximately 0.3 mile from the center of Rifle. The western site, known as New Rifle, is approximately 2 miles from the center of Rifle.

The uranium mill at the Old Rifle site operated from 1924-1958. After 1958, most of the Old Rifle tailings were reprocessed at the New Rifle site. The only structures remaining at the mill site are the assay building and the foundations of other mill facilities. From 1958 to 1973, the New Rifle mill produced uranium and vanadium. From 1973 to 1984, a portion of the mill was used to produce vanadium; this operation involved processing vanadium solutions and did not yield tailings. Both the Old and New Rifle tailings piles have been partially stabilized. The Old Rifle pile was recontoured, covered with six-inches of soil, and revegetated. The New Rifle was covered with fertilizer and mulch and revegetated.

The total amount of estimated volumes of tailings and contaminated materials at the Old and New Rifle sites is 4,135,000 cubic yards. The 22-acre Old Rifle tailings site consists of the 13-acre tailings pile and 9-acre mill area. Fifty-three acres adjacent to the tailings site are contaminated with windblown tailings and debris. The total amount of contaminated materials at the Old Rifle site, including contaminated soils beneath the tailings, is estimated to be 661,000 cubic yards. Seepage from the tailings pile has contaminated ground water in the alluvium and Wasatch Formation.

The New Rifle tailings site occupies 142 acres. The tailings pile covers 33 acres, and the mill area covers 59 acres. The entire New Rifle site is contaminated, and a 63-acre area adjacent to the tailings pile has been contaminated with windblown tailings. The total amount of contaminated materials at the New Rifle site, including contaminated soils beneath the tailings, is estimated to be 3,474,000 cubic yards, and includes contamination seepage from two vanadium ponds. Seepage from the tailings pile has contaminated ground water in the alluvium and Wasatch Formation.

4.2 DISCUSSION OF RESULTS

Discounted health risks and costs associated with the remedial alternatives for each subproject site are summarized in Table 4.1. Descriptions of each column heading and values from Fernald FEMP OU1 are provided below.

- Population deaths: The modeled population for each site consists of those individuals reasonably expected to come into contact with contamination from the site. For atmospherically-transported contaminants, all residents within a 50-mile radius were considered potential receptors. For groundwater and surface water contaminant transport pathways, the modeled population included actual users of the water for drinking, bathing, swimming, fishing, etc. The cumulative modeled population for a site is the sum of potential receptors modeled for each transport pathway. The population death value represents the number of cancer deaths that are predicted to occur within the next 7,000 years within the cumulative modeled population as a result of exposure to contaminants from the site without remediation. For example, 1.62 (rounded to 2) cancer deaths are predicted to occur over the next 7000 years in the modeled population exposed to contaminants from FEMP OU1. If one assumes that the population at FEMP OU1 is uniformly exposed over the 7000 years, only 0.02 cancer deaths would occur in any 70-year time period. However, because typical exposures do vary over time, the number of cancer deaths is very low or zero over certain time periods and higher over other time periods. When cancer deaths are summed over the 100 70-year periods, they total 2 deaths for FEMP OU1 over the next 7000 years.

  Note: The predicted number of cancer fatalities in a population exposed to airborne contaminants represent the fatalities predicted to occur over a 70-year time period as opposed to the 7000-year time period used to estimate fatalities from other contaminant transport pathways. The shorter time period is used because the airborne contaminants will reach peak concentration levels and dissipate within 70 years.

- Worker deaths: This value indicates the number of deaths occurring in the worker population involved in the implementation of each remedial alternative. The number of worker deaths includes deaths from occupational accidents as well as cancer deaths resulting from exposure to contaminants at the site. In general, the health impacts from occupational accidents are significantly greater than those from cancer due to radiation exposure to contaminants at the site. Worker deaths are calculated over the time period necessary to complete remediation. For example, Remedial Alternative 1 at FEMP OU1 generates a worker death value of 0.02. This value indicates the potential for 0.02 deaths among the workers involved in the implementation of Remedial Alternative 1 at FEMP OU1.

- Average individual risk: This value indicates the average 70-year lifetime risk of cancer fatality to an individual in the modeled population from exposure to contaminants from the site. The value is calculated by dividing the predicted number of population deaths by the size of the total population exposed over 7000 years. For example, FEMP OU1 is modeled with a 7000-year total exposed population of 2.67×10^{8} people. Dividing the number of predicted cancer deaths, 1.62, by this population yields an average 70-year lifetime cancer fatality risk of 6×10^{-9} to an individual in the exposed population.

- Average worker risk: This value represents the average risk of death for a remedial action worker, and is calculated by dividing the predicted number of worker deaths for each remedial alternative by the number of workers involved in the implementation of the remedial alternative. The average worker risk value includes the risk of death from occupational accidents as well as the risk of cancer fatality resulting from exposure to contaminants at the site. For example, a worker involved in the implementation of Remedial Alternative 1 at FEMP OU1 will have a 2×10^{-3} risk of fatality from an occupational accident or cancer resulting from exposure to contaminants at the site

- Reasonably exposed individual risk: This value represents the highest 70-year lifetime risk of cancer fatality to an individual within the modeled population under reasonable exposure conditions. The exposure conditions that generate the highest individual risk are realistic exposure conditions, not hypothetical worst-case exposure scenarios. For this reason, the values entered in this column are termed "reasonably exposed individual risk" as opposed to "maximum individual risk." For example, the highest 70-year lifetime risk of cancer fatality to an individual under reasonable exposure conditions in the modeled population exposed to contaminants from FEMP OU 1 is 8×10^{-2}. The reasonably exposed individual risk is higher than the average individual risk because the former represents the highest risk to an individual within the modeled population, whereas the latter represents the average risk to an individual within the modeled population.

- Uncertainty: This entry indicates the level of uncertainty associated with the risk estimates for each remedial alternative. A rating of "normal" indicates that risk estimates are based on adequate site characterization data, and uncertainty may span 1-2 orders of magnitude. An uncertainty rating of "high" indicates that risk estimates are based on limited site characterization data, and uncertainty may span 3-4 orders of magnitude.

- Risk reduction: This value represents the number of deaths avoided by the implementation of the remedial alternative. The risk reduction value incorporates both the reduction in the number of population cancer deaths as well as the increased number of worker fatalities generated by remedial alternative implementation. The risk reduction value is calculated by subtracting the worker death value from the number of population deaths avoided by the implementation of each remedial alternative. Parentheses enclosing the risk reduction value indicate a net increase in risk due to remedial action. That is, the number of deaths in the population of workers involved in remedial action is greater than the number of population deaths avoided. For example, FEMP OU 1 Remedial Alternative 1 reduces the population death value to zero, yet contributes 0.02 worker deaths during its implementation. The net risk reduction is 1.98 deaths (2 population deaths avoided - 0.02 worker deaths generated). This risk reduction number, rounded to the closest whole number, is entered as 2 in the risk reduction column of Table 5.1.

- Cost: This entry indicates the unescalated (FY 1991) cost associated with the implementation of each remedial alternative for each subproject.

Table 4.1(*a*). Discounted Health Risk and Cost Summary

Site Name	Remedial Alternative	Population Deaths*	Worker Deaths**	Average Individual Risk	Average Worker Risk	Reasonably Exposed Individual Risk	Uncertainty †	Risk Reduction ‡	Cost
Fernald FEMP OU1	No Action	2	0	6×10^{-9}	0	8×10^{-2}	Normal	0	$8,209,000
	1	0	2×10^{-2}	0	2×10^{-3}	0	Normal	2	$100,085,000
	2	0	1×10^{-2}	0	9×10^{-3}	0	Normal	2	$1,209,752,000
	3	0	1×10^{-2}	0	1×10^{-2}	0	Normal	2	$1,357,226,000
Fernald FEMP OU4	No Action	2	0	8×10^{-9}	0	4×10^{-4}	Normal	0	$8,962,000
	1	0	1×10^{-2}	0	6×10^{-3}	0	Normal	2	$244,846,000
	2	0	1×10^{-2}	0	9×10^{-3}	0	Normal	2	$76,001,000
	3	0	1×10^{-2}	0	8×10^{-3}	0	Normal	2	$93,755,000
LLNL Pit 6	No Action	2×10^{-5}	0	6×10^{-14}	0	7×10^{-10}	Normal	0	$0
	1	2×10^{-5}	N/A	6×10^{-14}	0	7×10^{-10}	Normal	0	$2,179,000
	2	2×10^{-5}	N/A	6×10^{-14}	0	7×10^{-10}	Normal	0	$2,887,000
	3	1×10^{-5}	N/A	3×10^{-14}	0	3×10^{-10}	Normal	1×10^{-5}	$6,040,000
LLNL Bldg. 834	No Action	4×10^{-4}	0	9×10^{-13}	0	1×10^{-4}	Normal	0	$0
	1	4×10^{-4}	N/A	9×10^{-13}	0	1×10^{-4}	Normal	0	$1,922,000
	2	1×10^{-4}	N/A	3×10^{-13}	0	7×10^{-5}	Normal	2×10^{-4}	$11,544,000
	3	1×10^{-4}	N/A	3×10^{-13}	0	7×10^{-5}	Normal	2×10^{-4}	$10,580,000
SR F&H Seepage Basins	No Action	0.1	0	1×10^{-7}	0	2×10^{-4}	Normal	0	$10,983,000
	1	0.08	6×10^{-2}	8×10^{-8}	3×10^{-3}	1×10^{-4}	Normal	(0.01)	$70,814,000
	2	0	6×10^{-2}	0	3×10^{-3}	0	Normal	0.1	$36,419,000
	3	0.04	6×10^{-2}	4×10^{-8}	3×10^{-3}	7×10^{-5}	Normal	0.1	$31,269,000
SR New TNX Seepage Basin	No Action	9×10^{-10}	0	2×10^{-17}	0	2×10^{-13}	High	0	$0
	1	2×10^{-11}	2×10^{-4}	3×10^{-17}	2×10^{-5}	2×10^{-13}	High	(2×10^{-4})	$1,157,000
	2	8×10^{-12}	2×10^{-4}	2×10^{-20}	2×10^{-5}	9×10^{-14}	High	(2×10^{-4})	$2,353,000
	3	0	5×10^{-4}	0	6×10^{-5}	0	High	(5×10^{-4})	$1,325,000

* Discounted cancer fatalities in exposed population over 7000 years

** Cancer and occupational accident fatalities in worker population

† "Normal"--risk estimates based on adequate site characterization data; uncertainty may span 1 – 2 orders of magnitude. "High"--risk estimates based on limited site characterization data; uncertainty may span 3 – 4 orders of magnitude.

‡ Population risk reduction due to remediation minus worker risk due to implementation of remedial alternative. ( ) indicates net risk increase

Table 4.1(*b*). Discounted Health Risk and Cost Summary

Site Name	Remedial Alternative	Population Deaths*	Worker Deaths**	Average Individual Risk	Average Worker Risk	Reasonably Exposed Individual Risk	Uncertainty †	Risk Reduction‡	Cost
SR M Area Settling Basin	No Action	6×10^{-1}	0	9×10^{-9}	0	2×10^{-2}	Normal	0	$2,996,000
	1	0	3×10^{-3}	0	3×10^{-4}	0	Normal	5×10^{-1}	$56,337,000
	2	9×10^{-2}	3×10^{-4}	1×10^{-9}	3×10^{-5}	2×10^{-2}	Normal	5×10^{-1}	$5,732,000
	3	9×10^{-2}	6×10^{-4}	1×10^{-9}	7×10^{-5}	2×10^{-2}	Normal	7×10^{-3}	$5,521,000
SR Sanitary Landfill	No Action	2×10^{-6}	0	4×10^{-14}	0	9×10^{-9}	High	0	$0
	1	7×10^{-8}	N/A	8×10^{-15}	0	4×10^{-10}	High	1×10^{-6}	$19,695,000
	2	2×10^{-6}	N/A	1×10^{-14}	0	1×10^{-9}	High	0	$6,514,000
	3	0	N/A	3×10^{-15}	0	5×10^{-10}	High	2×10^{-6}	$238,588,000
ORNL WAG 6	No Action	1	0	5×10^{-10}	0	5×10^{-6}	Normal	0	$0
	1	1×10^{-2}	2×10^{-2}	9×10^{-11}	6×10^{-4}	1×10^{-6}	Normal	0.05	$11,338,000
	2	0	3×10^{-2}	0	7×10^{-4}	0	Normal	(0.02)	$30,682,000
	3	0	3×10^{-2}	0	6×10^{-4}	0	Normal	(0.02)	$51,289,000
Y12 Bear Creek OU4	No Action	3×10^{-4}	0	2×10^{-11}	0	5×10^{-8}	Normal	0	$0
	1	0	2×10^{-2}	0	1×10^{-3}	0	Normal	(0.02)	$91,386,000
	2	3×10^{-4}	6×10^{-2}	1×10^{-11}	5×10^{-4}	4×10^{-8}	Normal	(0.006)	$3,874,000
	3	0	2×10^{-2}	0	1×10^{-3}	0	Normal	(0.02)	$16,913,000
K25 Pond Waste Mgmt.	No Action	3×10^{-3}	0	3×10^{-11}	0	2×10^{-7}	High	0	$0
	1	0	7×10^{-4}	0	5×10^{-6}	0	High	2×10^{-3}	$96,683,000
	2	0	3×10^{-2}	0	2×10^{-4}	0	High	(2×10^{-2})	$79,128,000
	3	0	3×10^{-2}	0	2×10^{-4}	0	High	(3×10^{-2})	$101,719,000
Y12 Bldg. 9201-4 (Alpha 4)	No Action	0	0	0	0	N/A	High	0	$0
	1	0	6×10^{-5}	0	2×10^{-5}	N/A	High	(6×10^{-5})	$5,390,000
	2	0	4×10^{-4}	0	2×10^{-5}	N/A	High	(4×10^{-4})	$103,584,000
	3	0	4×10^{-2}	0	9×10^{-4}	N/A	High	(0.02)	$716,067,000

* Discounted cancer fatalities in exposed population over 7000 years

* Cancer and occupational accident fatalities in worker population

† "Normal"–risk estimates based on adequate site characterization data; uncertainty may span 1 – 2 orders of magnitude. "High"–risk estimates based on limited site characterization data; uncertainty may span 3 – 4 orders of magnitude.

‡ Population risk reduction due to remediation minus worker risk due to implementation of remedial alternative. ( ) indicates net risk increase.

Table 4.1(*c*). Discounted Health Risk and Cost Summary

Site Name	Remedial Alternative	Population Deaths*	Worker Deaths**	Average Individual Risk	Average Worker Risk	Reasonably Exposed Individual Risk	Uncertainty †	Risk Reduction ‡	Cost
Argonne East 800 Area Landfill	No Action	2×10^{-4}	0	2×10^{-13}	0	1×10^{-8}	High	0	$6,799,000
	1	5×10^{-5}	2×10^{-2}	8×10^{-13}	9×10^{-4}	5×10^{-9}	High	(0.02)	$156,171,000
	2	3×10^{-5}	3×10^{-2}	5×10^{-13}	9×10^{-4}	5×10^{-9}	High	(0.03)	$346,247,000
	3	9×10^{-6}	1×10^{-2}	2×10^{-11}	1×10^{-3}	1×10^{-9}	High	(0.01)	$734,780,000
Argonne East 570 Holding Pond	No Action	3×10^{-10}	0	4×10^{-19}	0	4×10^{-15}	High	0	$3,288,000
	1	3×10^{-10}	9×10^{-8}	6×10^{-18}	7×10^{-5}	4×10^{-15}	High	(0.0009)	$3,437,000
	2	3×10^{-10}	5×10^{-2}	6×10^{-18}	9×10^{-4}	4×10^{-15}	High	(0.05)	$12,186,000
	3	0	1×10^{-2}	0	7×10^{-4}	0	High	(0.01)	$56,374,000
Argonne West Liquid Waste Processing	No Action	3×10^{-3}	0	3×10^{-6}	0	3×10^{-4}	High	0	$1,725,000
	1	0	3×10^{-4}	0	2×10^{-5}	0	High	0.003	$8,824,000
	2	0	3×10^{-4}	0	2×10^{-5}	0	High	0.003	$2,046,000
	3	0	4×10^{-4}	0	3×10^{-5}	0	High	0.003	$1,907,000
INEL BORAX V Facility	No Action	0	0	0	0	5×10^{-31}	High	0	$1,812,000
	1	0	8×10^{-3}	0	2×10^{-3}	0	High	(8×10^{-3})	$3,156,000
	2	0	9×10^{-4}	0	3×10^{-4}	0	High	(9×10^{-4})	$13,898,000
	3	0	1×10^{-3}	0	1×10^{-3}	0	High	(0.001)	$4,032,000
Los Alamos LAPRE Reactor	No Action	0	0	0	0	0	Normal	0	$0
	1	0	3×10^{-3}	0	3×10^{-4}	0	Normal	(0.003)	$198,000
	2	0	3×10^{-3}	0	3×10^{-4}	0	Normal	(0.003)	$212,000
	3	0	4×10^{-4}	0	6×10^{-5}	0	Normal	(0.004)	$141,000
Mound Miami-Erie Canal	No Action	2×10^{-3}	0	6×10^{-12}	0	3×10^{-7}	Normal	0	$0
	1	0	1×10^{-2}	0	4×10^{-4}	0	Normal	(8×10^{-3})	$13,297,000
	2	0	2×10^{-2}	0	6×10^{-4}	0	Normal	(2×10^{-2})	$23,166,000
	3	0	3×10^{-2}	0	1×10^{-3}	0	Normal	(3×10^{-2})	$424,257,000

* Discounted cancer fatalities in exposed population over 7000 years

** Cancer and occupational accident fatalities in worker population

† "Normal"--risk estimates based on adequate site characterization data; uncertainty may span 1 – 2 orders of magnitude. "High"--risk estimates were based on limited site characterization data; uncertainty may span 3 – 4 orders of magnitude.

‡ Population risk reduction due to remediation minus worker risk due to implementation of remedial alternative. ( ) indicates net risk increase

Table 4.1(*d*). Discounted Health Risk and Cost Summary

Site Name	Remedial Alternative	Population Deaths*	Worker Deaths**	Average Individual Risk	Average Worker Risk	Reasonably Exposed Individual Risk	Uncertainty†	Risk Reduction‡	Cost
Mound Area B Ground Water	No Action	3×10^{-1}	0	4×10^{-6}	0	1×10^{-4}	High	0	$0
	1	1×10^{-1}	1×10^{-2}	2×10^{-6}	1×10^{-3}	7×10^{-5}	High	1×10^{-1}	$148,444,000
	2	1×10^{-1}	1×10^{-2}	2×10^{-6}	1×10^{-3}	7×10^{-5}	High	1×10^{-1}	$193,001,000
	3	3×10^{-2}	2×10^{-3}	4×10^{-7}	4×10^{-4}	1×10^{-5}	High	3×10^{-1}	$13,019,000
SNL Fuel Oil Spill	No Action	0	0	0	0	N/A	High	0	$353,000
	1	0	0	0	0	N/A	High	0	$9,987,000
	2	0	0	0	0	N/A	High	0	$7,614,000
	3	0	0	0	0	N/A	High	0	$3,947,000
SNL Navy Landfill	No Action	0	0	0	0	0	Normal	0	$0
	1	N/A	N/A	0	0	0	Normal	N/A	$0
	2	N/A	N/A	0	0	0	Normal	N/A	$0
	3	N/A	N/A	0	0	0	Normal	N/A	$0
Hanford NRDWL	No Action	8×10^{-3}	0	2×10^{-10}	0	3×10^{-7}	Normal	0	$6,347,000
	1	0	N/A	0	0	0	Normal	8×10^{-3}	$14,350,000
	2	0	N/A	0	0	0	Normal	8×10^{-3}	$122,250,000
	3	0	N/A	0	0	0	Normal	8×10^{-3}	$195,210,000
UMTRA Gunnison	No Action	4×10^{-1}	0	9×10^{-8}	0	5×10^{-5}	High	0	$7,942,000
	1	0	4×10^{-2}	0	1×10^{-3}	0	High	4×10^{-1}	$253,028,000
	2	0	2×10^{-1}	0	3×10^{-3}	0	High	3×10^{-1}	$64,102,000
	3	0	5×10^{-1}	0	7×10^{-3}	0	High	(6×10^{-2})	$91,792,000
UMTRA Rifle	No Action	7	0	8×10^{-7}	0	7×10^{-5}	High	0	$15,530,000
	1	0	5×10^{-1}	0	4×10^{-3}	0	High	7	$84,393,000
	2	0	5×10^{-1}	0	9×10^{-3}	0	High	6	$84,174,000
	3	0	1	0	9×10^{-3}	0	High	6	$165,936,000

* Discounted cancer fatalities in exposed population over 7000 years

** Cancer and occupational accident fatalities in worker population

† "Normal"--risk estimates based on adequate site characterization data; uncertainty may span 1 – 2 orders of magnitude. "High"--risk estimates based on limited site characterization data; uncertainty may span 3 – 4 orders of magnitude

‡ Population risk reduction due to remediation minus worker risk due to implementation of remedial alternative. ( ) indicates net risk increase.

Table 4.2 provides a ranking of the 24 subprojects by discounted population fatalities. Sites in the upper grouping have predicted population fatalities greater than 1 over 7000 years. The middle grouping has between 1 and 0.0001 predicted population fatalities over 7000 years. The lower grouping has less than 0.0001 predicted population fatalities over 7000 years. Because of the uncertainty in risk estimates, it is not possible to distinguish among the rankings of sites within the same grouping.

Tables 4.3(a) and 4.3(b) provide rankings of the 24 subprojects by cost per fatality avoided, measured in discounted and undiscounted fatalities, respectively. In both tables, the subprojects in the upper grouping have a cost per fatality avoided of less than $100 million. The middle grouping has a cost per fatality avoided of between $100 million and $1,000 trillion. Sites in the lower grouping have no reduction in fatalities as a result of remedial action, thus making a computation of cost per fatality avoided impossible. As Table 4.3(b) illustrates, measuring population risk in undiscounted fatalities increases the number of sites having a cost per fatality avoided of less then $100 million. Furthermore, using undiscounted fatalities adds an additional site to the second grouping that previously showed no reduction in fatalities when using time discounted fatalities.

The MEPAS code allows health impacts to be estimated on either a time discounted basis or a non-time discounted (undiscounted) basis. The MEPAS time-discounting option was designed to emphasize the importance of near-term risks. A reduction of the risk magnitude by one-half per successive 70-year time period was chosen by DOE and the designers of MEPAS as the most appropriate discounting rate. This represents a decreasing risk of 0.995 or less than 1% per year. The undiscounted option does not reduce (discount) risks occurring in the distant future. The use of undiscounted estimates allows risks occurring late in the 7000-year period to be presented as equivalent risks occurring in the near future.

It is important to note that the MEPAS code estimates risk from exposure to airborne contaminants for a period of 70 years as opposed to the 7000-year period used to estimate risk from contaminants transported through other media. A period of 70 years is examined because the airborne contaminants will reach peak concentrations and dissipate within 70 years. Because only risks estimated to occur after the first 70-year time period are discounted using the time discounting option, the time discounted risks resulting from exposure to airborne contaminants will be the same as the non-time discounted risk. Table 4.4 compares the discounted and undiscounted population deaths and average individual risks. Values from Fernald OU1 and OU4 are discussed below to illustrate the difference between discounted and undiscounted risk estimates.

At Fernald OU1, 3 deaths are calculated to occur from exposure to contaminants from the site if the time discounting option is not used. If the time discounting option is used, the result is 2 deaths. The change can be explained by examining the nature of contaminant transport from FEMP OU1. The contaminant transport pathway contributing the greatest risk to the exposed population involves the seepage of contaminants from FEMP OU1 into the underlying soils and migration of the contaminants to the ground water, a source of drinking water. Because the migration of the contaminants through the soil layers and subsequent movement of contaminants in the ground water are slow processes, the contaminants will not reach peak concentrations at the receptor site (i.e., at a well used to collect ground water for use as drinking water) until some time within the second 70-year time period examined (between 71 and 140 years from the present). Hence, the fatalities are expected to occur in the second time period. Because the fatalities are expected to occur in the second 70-year time period, the magnitude of the predicted discounted fatalities is approximately one-half the magnitude of the true undiscounted estimate.

The number of estimated time discounted and undiscounted fatalities associated with the no-action alternative at Fernald OU4 are identical. Again, this pattern can be explained by examining the nature of contaminant transport from the waste site. The only significant contributor of risk from OU4 is exposure to airborne radon. As noted previously, the MEPAS code estimates risks (and fatalities) from exposure to airborne contaminants for a period of 70 years. Hence, no estimates of risk resulting from exposure to airborne contaminants are predicted for time periods after the first 70-year period. Because the time discounting option reduces the estimate of the risks after the first 70-year period, the estimate of the risks associated with exposure to airborne contaminants will not be reduced by the time discounting option. Hence, the predicted discounted and undiscounted fatalities resulting from exposure to airborne radon from Fernald OU4 are identical.

Table 4.2 Subproject Rank by Discounted Population Baseline Risk

Site Name	Baseline Risk (Fatality)
UMTRA: Rifle	POPULATION FATALITIES GREATER THAN 1
Fernald: FEMP OU4	
Fernald: FEMP OU1	
Mound: Area B	POPULATION FATALITIES BETWEEN 1—.0001
Savannah River: F & H	
Savannah River: M Area	
LLNL Bldg. 834	
ORNL WAG 6	
Argonne West: Liquid Waste	
UMTRA: Gunnison	
Hanford: NRDWL	
K25: Pond Waste	
Mound: Miami-Erie Canal	
Y12: Bear Creek OU4	
Argonne East: 800	
LLNL 300: Pit 6	POPULATION FATALITIES LESS THAN .0001
Savannah River: Sanitary Landfill	
Savannah River: New TNX	
Argonne East: 570 Holding Pond	
Y12: Bldg. 9201-4 (Alpha 4)	
INEL: BORAX-V	
Los Alamos: LAPRE	
Sandia-Livermore: Fuel Oil Spill	
Sandia-Livermore: Navy Landfill	

Table 4.3(a) Cost per Discounted Fatality Avoided

Site Name	Dollar/Reduced Fatality
Fernald FEMP OU1	COST PER FATALITY AVOIDED LESS THAN 10^8
Fernald FEMP OU4	
Savannah River M Area	
Mound Area B Groundwater	
UMTRA: Rifle	
Savannah River F&H Area	COST PER FATALITY AVOIDED BETWEEN 10^8-10^{15}
Savannah River Sanitary Landfill	
ORNL WAG 6	
ORR: Pond Waste Management (K25)	
Hanford NRDWL	
LLNL 300 Bldg. 834	
LLNL 300 Pit 6	
UMTRA: Gunnison	
Argonne West Liquid Waste Process	
Savannah River New TNX Basin	NO REDUCTION IN FATALITY
ORR: Y12 Bldg. 9201-4 (Alpha 4)*	
ORR: Y12 Bear Creek OU4	
Sandia Livermore Fuel Oil Spill*	
Sandia Livermore Navy Landfill*	
INEL BORAX-V*	
Los Alamos LAPRAE*	
Argonne East 800 Area Landfill	
Argonne East 570 Holding Pond	
Mound Miami-Erie Canal	

* No predicted baseline population risk

Table 4.3(b) Cost per Undiscounted Fatality Avoided

<table>
<tr><th>Site Name</th><th>Dollar/Reduced Fatality</th></tr>
<tr><td>FEMP OU1</td><td rowspan="6">COST PER FATALITY AVOIDED LESS THAN 10^8</td></tr>
<tr><td>FEMP OU4</td></tr>
<tr><td>Savannah River M Area</td></tr>
<tr><td>Mound Area B Groundwater</td></tr>
<tr><td>UMTRA: Rifle</td></tr>
<tr><td>Savannah River F&H Area</td></tr>
<tr><td>Savannah River Sanitary Landfill</td><td rowspan="9">COST PER FATALITY AVOIDED BETWEEN 10^8-10^{15}</td></tr>
<tr><td>ORNL WAG 6</td></tr>
<tr><td>ORR: Pond Waste Management (K25)</td></tr>
<tr><td>Hanford NRDWL</td></tr>
<tr><td>LLNL 300 Bldg. 834</td></tr>
<tr><td>LLNL 300 Pit 6</td></tr>
<tr><td>UMTRA: Gunnison</td></tr>
<tr><td>Argonne West Liquid Waste</td></tr>
<tr><td>Argonne East 800 Area</td></tr>
<tr><td>Savannah River New TNX</td><td rowspan="9">NO REDUCTION IN FATALITY</td></tr>
<tr><td>ORR: Y12 Bldg. 9201-4 (Alpha 4)*</td></tr>
<tr><td>ORR: Y12 Bear Creek OU4</td></tr>
<tr><td>Sandia Livermore Fuel Oil Spill*</td></tr>
<tr><td>Sandia Livermore Navy Landfill*</td></tr>
<tr><td>INEL BORAX-V*</td></tr>
<tr><td>Los Alamos LAPRE</td></tr>
<tr><td>Argonne East 570 Holding Pond</td></tr>
<tr><td>Mound Miami-Erie Canal</td></tr>
</table>

* No predicted baseline population risk

Table 4.4(a). Time Discounted and Undiscounted Population Deaths and Average Individual Risk

Site	Remedial Alternative	Time Discounted		Undiscounted	
		Population Deaths	Average Individual Risk	Population Deaths	Average Individual Risk
Fernald OU1	No Action	2	6×10^{-9}	3	9×10^{-13}
	1	0	0	0	0
	2	0	0	0	0
	3	0	0	0	0
Fernald OU4	No Action	2	8×10^{-9}	2	8×10^{-13}
	1	0	0	0	0
	2	0	0	0	0
	3	0	0	0	0
LLNL Pit 6	No Action	2×10^{-5}	6×10^{-14}	3×10^{-3}	8×10^{-12}
	1	2×10^{-5}	6×10^{-14}	3×10^{-3}	8×10^{-12}
	2	2×10^{-5}	6×10^{-14}	3×10^{-3}	8×10^{-12}
	3	1×10^{-5}	3×10^{-14}	1×10^{-3}	3×10^{-16}
LLNL Bldg. 834	No Action	4×10^{-4}	9×10^{-13}	4×10^{-4}	9×10^{-13}
	1	4×10^{-4}	9×10^{-13}	4×10^{-4}	9×10^{-13}
	2	1×10^{-4}	3×10^{-13}	1×10^{-4}	3×10^{-13}
	3	1×10^{-4}	3×10^{-13}	1×10^{-4}	3×10^{-13}
SR F&H Seepage Basins	No Action	1×10^{-1}	1×10^{-7}	6×10^{-1}	7×10^{-7}
	1	8×10^{-2}	8×10^{-6}	2	2×10^{-6}
	2	0	0	0	0
	3	0.04	4×10^{-8}	0.8	8×10^{-7}
SR New TNX Seepage Basin	No Action	9×10^{-10}	2×10^{-17}	7×10^{-9}	1×10^{-16}
	1	2×10^{-11}	3×10^{-17}	4×10^{-9}	6×10^{-15}
	2	8×10^{-12}	2×10^{-20}	2×10^{-9}	4×10^{-18}
	3	0	0	0	0

Table 4.4(b) Time Discounted and Undiscounted Population Deaths and Average Individual Risk

Site	Remedial Alternative	Time Discounted		Undiscounted	
		Population Deaths	Average Individual Risk	Population Deaths	Average Individual Risk
SR M Area Settling Basin	No Action	6×10^{-1}	9×10^{-9}	1	2×10^{-8}
	1	0	0	0	0
	2	9×10^{-2}	1×10^{-9}	3	4×10^{-8}
	3	9×10^{-2}	1×10^{-9}	3	4×10^{-8}
SR Sanitary Landfill	No Action	2×10^{-6}	4×10^{-14}	4×10^{-3}	8×10^{-11}
	1	5×10^{-7}	8×10^{-15}	5×10^{-4}	8×10^{-12}
	2	6×10^{-7}	1×10^{-14}	2×10^{-3}	4×10^{-11}
	3	8×10^{-8}	3×10^{-15}	6×10^{-4}	2×10^{-11}
ORNL WAG 6	No Action	6×10^{-2}	5×10^{-10}	2×10^{-1}	2×10^{-9}
	1	1×10^{-2}	9×10^{-11}	3×10^{-2}	3×10^{-10}
	2	0	0	0	0
	3	0	0	0	0
Y12 Bear Creek OU4	No Action	3×10^{-4}	2×10^{-11}	3×10^{-4}	2×10^{-11}
	1	0	0	0	0
	2	3×10^{-4}	1×10^{-11}	3×10^{-4}	1×10^{-11}
	3	0	0	0	0
K25 Pond Waste Mgmt.	No Action	3×10^{-3}	3×10^{-11}	5×10^{-3}	4×10^{-11}
	1	0	0	0	0
	2	0	0	0	0
	3	0	0	0	0
Y12 Bldg. 9201-4 (Alpha 4)	No Action	0	0	0	0
	1	0	0	0	0
	2	0	0	0	0
	3	0	0	0	0

Table 4.4(c). Time Discounted and Undiscounted Population Deaths and Average Individual Risk

Site	Remedial Alternative	Time Discounted		Undiscounted	
		Population Deaths	Average Individual Risk	Population Deaths	Average Individual Risk
Argonne East 800 Area Landfill	No Action	2×10^{-4}	2×10^{-13}	0.8	8×10^{-10}
	1	5×10^{-5}	8×10^{-13}	0.4	7×10^{-9}
	2	5×10^{-5}	5×10^{-13}	0.4	4×10^{-9}
	3	9×10^{-6}	2×10^{-11}	0.08	1×10^{-7}
Argonne East 570 Holding Pond	No Action	3×10^{-10}	4×10^{-19}	7×10^{-6}	1×10^{-15}
	1	3×10^{-10}	6×10^{-18}	7×10^{-6}	5×10^{-14}
	2	3×10^{-10}	6×10^{-18}	7×10^{-6}	5×10^{-14}
	3	0	0	0	0
Argonne West Liquid Waste Processing	No Action	0.003	3×10^{-6}	0.003	3×10^{-6}
	1	0	0	0	0
	2	0	0	0	0
	3	0	0	0	0
INEL BORAX-V	No Action	0	0	0	0
	1	0	0	0	0
	2	0	0	0	0
	3	0	0	0	0
Los Alamos LAPRE Reactor	No Action	0	0	0	0
	1	0	0	0	0
	2	0	0	0	0
	3	0	0	0	0
Mound Miami-Erie Canal	No Action	2×10^{-3}	6×10^{-12}	2×10^{-3}	6×10^{-12}
	1	0	0	0	0
	2	0	0	0	0
	3	0	0	0	0

Table 4.4(d). Time Discounted and Undiscounted Population Deaths and Average Individual Risk

Site	Remedial Alternative	Time Discounted		Undiscounted	
		Population Deaths	Average Individual Risk	Population Deaths	Average Individual Risk
Mound Area B Ground Water	No Action	3×10^{-1}	4×10^{-6}	14	2×10^{-4}
	1	1×10^{-1}	2×10^{-6}	7	1×10^{-4}
	2	1×10^{-1}	2×10^{-6}	7	1×10^{-4}
	3	3×10^{-2}	4×10^{-6}	1	1×10^{-5}
SNL Fuel Oil Spill	No Action	0	0	0	0
	1	0	0	0	0
	2	0	0	0	0
	3	0	0	0	0
SNL Navy Landfill	No Action	0	0	0	0
	1	0	0	0	0
	2	0	0	0	0
	3	0	0	0	0
Hanford NRDWL	No Action	8×10^{-3}	2×10^{-10}	3×10^{-2}	6×10^{-10}
	1	0	0	0	0
	2	0	0	0	0
	3	0	0	0	0
UMTRA Gunnison	No Action	3×10^{-2}	9×10^{-8}	2	6×10^{-6}
	1	0	0	0	0
	2	0	0	0	0
	3	0	0	0	0
UMTRA Rifle	No Action	7	8×10^{-7}	7	8×10^{-7}
	1	0	0	0	0
	2	0	0	0	0
	3	0	0	0	0

A comparison of MEPAS risk estimates with other risk assessment results is contained within Table 4.5. Descriptions of each column heading and values from Fernald FEMP OU1 are provided below.

- Site: This entry indicates the subproject at the installation under consideration.

- Constituent: This entry indicates the primary contaminant contributing to risk for the subproject under consideration. Other contaminants may be present at the subproject site but they contribute less significant health risks.

- Exposure Pathway: This entry indicates the primary pathways of environmental transport and subsequent human exposure considered in the comparison of MEPAS risk values with those of other risk assessments. For example, ground water ingestion, swimming and inhalation exposure pathways were considered in both the MEPAS risk assessment and comparison risk assessment.

- Individual Risk: The Individual Risk entry is subdivided into two columns. The first column beneath the heading of Individual Risk lists MEPAS-generated risk values, which indicate the highest 70 year lifetime risk of cancer fatality to an individual within the modeled population under reasonable exposure conditions. The second column beneath the Individual Risk heading lists comparison risk values, which indicate the 70 year lifetime risk of cancer fatality as computed by a comparison risk assessment.

- Source: This entry provides the reference for the comparison risk assessment.

Table 4.5(a) Comparison of MEPAS Risk Estimates with other Risk Assessment Results

Installation	Site	Constituent	Exposure Pathway	Individual Risk		Source
				MEPAS Value	Comparison Value	
Fernald FEMP	OU1	U-238	Ground Water Ingestion	2×10^{-1}	2.5×10^{-2}	RI, 1990
			Swimming	2×10^{-8}	N/A	
			Inhalation	3×10^{-6}	3×10^{-5} (Cumulative)	
	OU4	Radon-222	Inhalation	3×10^{-4}	5×10^{-3}	
		Radiation	Direct Exposure	7×10^{-5}	$.3 \times 10^{-4}$	
UMTRA Gunnison	Goodwine Lane	U-234	Ground Water Ingestion	4×10^{-5}	5.1×10^{-5}	DOE-UMTRA, ALBQ, 1990
		U-238	Ground Water Ingestion	3×10^{-5}	4.5×10^{-5}	
	Dos Rios	U-234	Ground Water Ingestion	1×10^{-5}	1.7×10^{-6}	
		U-238	Ground Water Ingestion	1×10^{-5}	1.5×10^{-6}	
Hanford	NRDWL	Benzene, Methylene Chloride	Ground Water Ingestion	1×10^{-6}	N/A	Golder Assoc., Inc., 1990
			Surface Water Ingestion	3×10^{-10}	7×10^{-9}	
			Inhalation	9×10^{-12}	2.2×10^{-7}	

Table 4.5(b) Comparison of MEPAS Risk Estimates with other Risk Assessment Results

Installation	Site	Constituent	Exposure Pathway	Individual Risk		Source
				MEPAS Value	Comparison Value	
LLNL	Bldg. 834 Complex	TCE	Ground Water Ingestion	2×10^{-4} (Hypothetical)	N/A	RI, 1990
			Inhalation	5×10^{-10}	2×10^{-7}	
	Landfill Pit 6		Ground Water Ingestion	7×10^{-8} (Hypothetical)	1×10^{-5} (Hypothetical)	
			Inhalation	7×10^{-15}	N/A	
Savannah River	New TNX Seepage Basin	Chloroform	Inhalation	5×10^{-15}	3×10^{-14}	Environmental Information Document
			Surface Water Ingestion	4×10^{-13}	3×10^{-14}	
	F&H Seepage Basins	Tritium, Iodine-129	Ground Water Ingestion	4×10^{-4}	1×10^{-5}	
			Surface Water	2×10^{-8} (Food Chain)	4×10^{-9} (Ingestion)	
	M Area Settling Basin	PCE	Ground Water Ingestion	2×10^{-2}	2×10^{-1}	
			Surface Water Ingestion	2×10^{-7}	7×10^{-8}	
			Inhalation	6×10^{-8}	2×10^{-8}	

5. CONCLUSIONS AND RECOMMENDATIONS

5.1 OVERVIEW

OMB requested that DOE develop a risk- and cost-estimating process for subprojects within DOE's ER Program. OMB requested the inclusion of 24 subprojects selected from a population of over 525 ER subprojects, approximately 350 of which are remedial or decontamination and decommissioning subprojects. For each subproject, the health risk and cost of a no-action and three remedial alternatives were estimated.

OMB requested that the study include subprojects in various stages of characterization and remediation, containing environmental and source term data of different levels of quality. Consequently, some of the 24 subprojects selected in this study were in the early stages of investigation and lacked a well defined scope of work for remedial action (e.g., identification of hazardous contaminants of concern, presence of radionuclides, quantity of hazardous materials, and selection of remedial technology). In these cases, the estimates were developed on the basis of assumptions that established scope. Consequently, the risk and cost estimates are subject to revision as additional information is identified that could eliminate the need for, or change the basis of assumptions.

The study predicts time-discounted baseline population risks ranging from zero to seven fatalities (over 7,000 years) per subproject within this 24 subproject analysis, with 83 percent of the sites having a predicted baseline population risk of less than one fatality. The predicted risk reduction achieved through remedial action varied considerably from complete reduction at some sites to a net increase in risk at others. The average cost of remedial action is predicted to be on the order of $100 million. As illustrated in Table 4.3(a), the predicted cost per discounted fatality avoided through remedial action is equal to or greater than $100 million at over half of the sites where remedial action reduces the number of predicted fatalities.

The primary conclusion of the study, as detailed within the report's tables and associated narrative, is that projected population and average individual risks over 7000 years from the 24 subprojects are small. Furthermore, risks associated with remediation of the 24 subprojects are generally comparable to existing baseline levels of risk to the surrounding populations. Thus, in many cases, the number of deaths in the worker population involved in remedial action is projected within this pilot study to be equal to or greater than the number of deaths avoided (through the implementation of currently available remedial alternatives) in the surrounding population over 7000 years. Another finding of the study is that worker risk associated with remediation results primarily from occupational accidents during the remediation process rather than from radiation exposures. These last two findings may not be generally applicable because of the pilot study's small sample and restricted scope and the limitations of currently available remediation technology and information from site characterization. However, these findings alert DOE to the need to continue to carefully assess projected occupational risks of proposed remediation alternatives and take measures to reduce them.

A significant weakness of ranking subprojects based on risk is the inability to measure the contribution of site characterization and assessment activities to achieving overall programmatic objectives. Since the ER program is currently expending the majority of its resources on site characterization and assessment and will continue to do so for some time, the results of this study are unlikely to play a significant role in future budget decision-making. Consequently, the results of this study may be useful for evaluating various funding profiles for projects in the cleanup phase, but provide little insight into the decision to fund assessment activities.

5.2 RISK

Based on the results of the study, the following recommendations are made.

5.2.1 Uncertainty

The study found that estimates of risk are subject to significant uncertainty, and it is recommended that a sensitivity and uncertainty analysis be performed on the risk-based ranking produced for this study. A sensitivity analysis of MEPAS would be performed to identify model parameters that most affect estimates of risk; probability distributions would be developed for the most sensitive parameters. A statistical analysis would be performed using data from 6 to 8 selected subprojects to determine whether statistically significant differences exist in the risk estimates produced by MEPAS.

5.2.2 Limitations of Risk Model

MEPAS was selected as the most appropriate code to estimate risk for this study. The exposure assessment portions of MEPAS are based on models recommended by EPA and NRC and thus appears adequate for estimating environmental concentrations associated with environmental restoration problems. There are two difficulties, however, associated with the application of MEPAS in this study. The first is the lack of adequate site characterization data at some sites, and the second is that the MEPAS model is not directly designed to evaluate risk reduction associated with remediation. The second issue is addressed first.

- MEPAS cannot directly simulate certain remedial action alternatives, including capping and the pumping of ground water. This is the most serious deficiency of the current version of the model. Should MEPAs be used again for this type of analysis then it is recommended that the MEPAS model be modified to account for decreased infiltration and decreased leaching rates that result from capping and the decrease in future ground water contaminant concentrations that result from remedial pumping of ground water.

- MEPAS does not adequately estimate environmental releases of contaminants from the waste units. For example, the model cannot calculate a contaminant leaching rate for the time period beyond the period of use of the waste unit. Should MEPAS be used again for this type of analysis then it is recommended that the MEPAS code be modified in order to provide more realistic estimates of contaminant releases from waste units.

- In certain situations, MEPAS overestimates population risk. MEPAS divides the modeled population into a number of subpopulations that receive different exposures. For each subpopulation, MEPAS generates a maximum population risk, not an average population risk. Should MEPAS be used again for this type of analysis then it is recommended that MEPAS be modified to calculate average population risk.

- MEPAS cannot simulate certain complicated contaminant transport pathways (e.g., Surface Water → Overland Runoff → Surface Water → Ground Water). Should MEPAS be used again for this type of analysis then it is recommended that MEPAS be modified to provide realistic simulations of all contaminant transport pathways encountered at DOE facilities.

- MEPAS cannot adequately describe certain complex subsurface conditions. Should MEPAS be used again for this type of analysis then it is recommended that MEPAS be modified to describe perched and multiple aquifers that occur at DOE sites.

In addition, the risk estimates for D&D subprojects in this study do not currently account for environmental impacts resulting from catastrophic accidents or fires. It is recommended that such events be considered in the estimation of D&D risks.

5.2.3 Lack of Familiarity with Sites

The lack of site familiarity and insufficient communication between risk assessors and site personnel have been identified as major causes of error using the MEPAS model, and a recent evaluation of the use of MEPAS (Shevenell and Hoffman 1991) indicated that the inconsistency of user assumptions is the predominate cause of risk estimate errors. If this type of analysis is conducted in the future, it is recommended that a risk assessment coordinating team (2-3 people) be established for each site that would visit the site and develop an interactive relationship with site personnel. The ongoing exchange of information between site officials and risk assessors would provide the risk assessors with the most accurate information regarding contaminant concentrations, contaminant transport, and proposed remedial alternatives.

5.3 COST

Existing cost and engineering data were used to the greatest extent possible, but the methodological framework specified by OMB required that all cost estimates be prepared and presented in a consistent manner. Many of the subprojects examined in this study did not yet have estimates of cleanup cost and this required the development of completely new cost estimates. In other cases, Field Office estimates were reformatted to achieve the degree of consistency required for this study. Both the cost data and the cost estimates provided by the Field Offices lacked consistency in areas such as material cost, indirect cost, and contingency. DOE's Office of Environmental Restoration has conducted self assessments and knows that improved cost-estimate consistency will only be achieved through a combination of clear, detailed guidance and appropriate tools and methods with which to implement the guidance. The ER Program's existing cost-estimating guidance incorporates the experience of these self assessments, as well as the lessons learned in this study. Many cost-estimating challenges that existed at the time of the 1991 Program Cost Review have been addressed, and detailed direction has been provided to define the preferred approaches to cost estimating for application by the Field Offices. Additionally, DOE's cost-estimating guidelines establish the minimum level of detail required at each stage of project development beginning in assessment and continuing into cleanup. This approach not only achieves the objective of improved consistency, but also minimizes the impact on the field by placing all cost-estimating requirements in a single directive within the established line management organization.

5.3.1 Improved Cost-estimating Methods

This study selected a detailed cost-estimating model because of its ability to accommodate a wide range of data representing different locations, varying contaminants, and a wide range of remedial technologies. The goal of improved estimate consistency and traceability can be enhanced through the development of tools and methods that allow cost estimators to organize and present their data without sacrificing accuracy. Additionally, these tools should be suitable for all types of estimates ranging from preconceptual to definitive in the level of detail to be used in projects from the planning phase to the execution phase. The COSTPRO system used for this study includes the following features that all contribute to its utility for DOE environmental cost estimates:

- uses a multiple attribute coding system to report costs in multiple formats such as the WBS, the Code of Accounts, and the B&R code;
- builds a custom unit cost data base and accesses commercially available data bases such as M-CACES;
- prepares detailed and summary reports quickly and in a wide range of formats; and
- is already in wide use throughout DOE.

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